U.S. Department of Transportation

Suggested Procedures for Evaluating the Effectiveness of Freeway HOV Facilities

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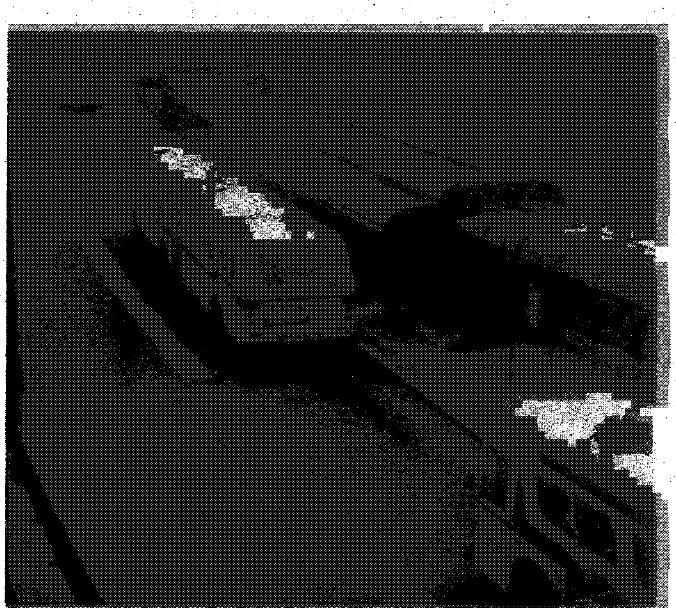


Suggested Procedures for Evaluating the Effectiveness of Freeway HOV Facilities

Final Report
February 1991

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I. INTRODUCTION

The Texas Transportation Institute (TTI), a part of The Texas A&M University System, is conducting an assessment of high-occupancy vehicle (HOV) lane projects located either on freeways or in separate rights-of-way in North America. The three-year research study is being funded by the Urban Mass Transportation Administration through the Texas State Department of Highways and Public Transportation (SDHPT). One of the major elements of the assessment focuses on evaluating the effectiveness of operating HOV facilities. To provide a comprehensive examination of the issues associated with evaluating operating HOV projects, a review of current before-and-after evaluation practices has been conducted. This review provides an overview of the objectives of HOV facilities, commonly used evaluation measures, measurement techniques, and data collection methodologies. The outcome of these activities is the development of a suggested approach and procedures for evaluating freeway HOV projects.

This report presents the results of the state-of-the-art review of evaluation practices used with different HOV projects in North America. Further, it outlines suggested procedures for conducting before-and-after evaluations of freeway HOV facilities and ongoing monitoring activities. It is anticipated that the suggested procedures will provide a national model for application with all types of freeway HOV projects. This should enhance project specific before-and-after studies and provide a comparable and compatible data base for HOV projects.

Background

Evaluating the impact of HOV facilities has been a topic of interest and discussion among transportation professionals in recent years. Potential evaluation criteria, appropriate effectiveness measures, evaluation methodologies, and data collection activities have been a major focus of sessions at recent TRB Annual Meetings and National HOV Conferences, as well as numerous reports. While there appears to be general agreement among transportation professionals that HOV facilities should be evaluated, a consensus does not appear to exist regarding the most appropriate measures to use, the performance thresholds the projects should meet to be considered effective, or the data collection techniques. To date, the evaluations that have been conducted have often focused on general evaluation criteria and, given the nature of many of the facilities and limited funding for data collection, before-and-after evaluations have often been limited. In some cases, this has resulted in insufficient data to make meaningful comparisons. In addition, the lack of uniformity between approaches used in different areas has made comparisons between projects difficult.

The need to conduct accurate evaluations of HOV facilities is generally recognized by transportation professionals. Evaluations are necessary to ensure that the improvements are providing the desired benefits, and that the expenditure of public funds is justified. Interest exists in the results of these evaluations among not only the transportation community, but also among decision makers, special interest groups, and the general public. The challenge to transportation professionals is to provide accurate and objective evaluations of HOV facilities that focus on key criteria and that can be easily understood by all groups.

Given the results of the research conducted to date, it does not appear that this point has been reached. While the approaches used in evaluating HOV facilities have improved over the years, weaknesses still exist. The analysis contained in the report and the suggested procedures for evaluating freeway HOV facilities should enhance the state-of-the-art practices. Use of the suggested procedures can improve the focus and quality of evaluations and provide a standardization that will allow for meaningful comparisons between projects.

Organization of This Report

Following the introduction, this report is organized into five sections. The next section provides an overview of the purpose and benefits of conducting evaluations of HOV projects. Chapter 3 summarizes the results of the literature review of past and current practices associated with evaluating HOV facilities. Chapter 4 presents a discussion of an overall approach that appears appropriate for conducting evaluations of freeway HOV facilities; this includes the identification of the appropriate objectives for HOV projects, the corresponding measures of effectiveness, measurement techniques, and data collection methodologies. Chapter 5 outlines in more detail the suggested procedures for collecting and analyzing the data needed to conduct the evaluation; this includes suggested approaches and procedures for collecting, analyzing, and presenting data. A discussion of the major issues associated with data collection activities is also presented in this section, along with a guide to how limited resources can best be allocated to ensure at least a basic level of analysis. The last chapter provides concluding comments on the suggested evaluation process. Additional information on specific topics discussed in the report is provided in the appendices; a bibliography of the sources examined is also included.

II. PURPOSE AND BENEFITS OF HOV PROJECT EVALUATIONS

Purpose and Scope of HOV Project Evaluations

Evaluations of transportation projects provide an opportunity to compare alternatives, measure the worth or value of a project, and determine if the goals of a project have been met. Evaluations are usually conducted at different stages in the project development and implementation process. Initially, competing alternatives are examined and evaluated to assist with the selection of the preferred approach. Once the decision has been made on a specific course of action, before-and-after evaluations are conducted to determine if the anticipated benefits have in fact been realized and to assist in identifying ways to improve similar projects in the future. Further, ongoing monitoring and periodic evaluations are often undertaken to ensure that the project continues to meet the desired goals and to identify possible areas for improvement.

Evaluations of HOV facilities are often conducted for similar purposes. First, an HOV facility may be one of many alternatives considered in the planning stage of a project. Second, once selected as the preferred alternative and implemented, evaluations may be conducted after an initial demonstration or start-up phase. Evaluations at this point focus on identifying if the benefits estimated for the facility are being realized. Finally, ongoing monitoring and periodic evaluations may be conducted on the HOV facility to ensure that these benefits continue to be realized and to improve the operation of the lane. To date, ongoing evaluations of HOV projects have been limited. Thus, HOV facilities can be evaluated as one of many alternatives during the planning stage, shortly after implementation, and on an ongoing basis.

The focus of this report is on evaluating operating HOV facilities. Thus, the report is primarily concerned with a comparison of conditions before the HOV project is constructed and those after implementation, and the ongoing monitoring of the facility. However, it is important to note that much of the information generated during the analysis of alternatives may also be used in the before-and-after evaluation. The results of this analysis, which often include the use of simulation models or other forecasting techniques, may form the basis for comparison with the actual operation of the facility. In addition, other measures, such as the UMTA cost-effectiveness index, may be used in evaluating alternatives. Thus, a link exists between the different stages of evaluations.

Benefits of Conducting Before-and-After Evaluations

Multiple benefits can be realized from conducting before-and-after studies of HOV projects. Evaluations provide the ability to determine if the goals and objectives of the project have been achieved. In addition, the information obtained from the evaluation process has numerous secondary benefits. This section provides a brief summary of the reasons for conducting HOV project evaluations and the benefits resulting from these efforts.

A main reason for conducting before-and-after evaluations of HOV projects is to identify the benefits accrued from the project and to determine how well the goals and objectives identified for the facility are being met. Evaluations provide an opportunity to ascertain the degree to which the desired results are in fact occurring. Further, before-and-after studies provide an official data base for the project. This can help ensure that all groups are utilizing the same data and can help to clarify any possible disagreements over the impact of the project.

The results of before-and-after studies are also important in future planning efforts within the metropolitan area. The information generated can be used to calibrate planning and simulation models for future use and can be used to assist in the decision making process in other corridors. Planning and simulation models are often used in the analysis of alternatives. Utilizing the results from the before-and-after studies to modify these to more accurately reflect actual experience provides a valuable check on the modeling process and improves the future capabilities of the models. In addition, the results from the evaluation and the experience gained from the project can enhance the decision making process on future projects.

The information collected as part of the evaluation process has value for operating decisions relating to the HOV facility. Information on usage, violation rates, and accidents are all critical for ensuring the efficient and safe operation of the facility. Monitoring these and other aspects of the HOV lane as part of the evaluation process can identify problems that may need to be addressed. For example, changes in operating hours, vehicle occupancy requirements, bus service levels, and access/egress points may be necessary. Thus, the data provided from before-and-after studies, especially longitudinal data on the use of the facility, serves a critical operations function. This information can also be used to evaluate the marketing and public information programs associated with the facility and identify if additional marketing is needed.

Evaluations may also be needed to meet federal or state requirements. A variety of funding sources have been used to implement HOV projects. Different funding sources and programs may require before-and-after evaluations. Even when not a requirement, evaluations of HOV projects can serve a useful purpose to assist in justifying future funding for similar facilities.

Lastly, by providing information on different projects throughout the country, the results of evaluation studies can assist in establishing an ongoing national data base on HOV facilities. Building a common body of knowledge on the use and effectiveness of HOV facilities is needed to continue to keep pace with the issues facing transportation professionals and decision makers in urban areas. A common national data base on HOV facilities can assist in ensuring that all areas are kept informed of the latest developments in the field.

Audiences for HOV Evaluations

The results of HOV project evaluations are of interest to a variety of groups. These include transportation professionals and technical staff, decision makers, special interest groups, the general public, and federal agencies. In general, these groups can be divided into two categories; those with a technical orientation and those with a more general focus. Given the diverse nature of these two groups, it may be appropriate to use different formats and approaches to present the results of the evaluation process. As with any report, the scope, content, and level of detail should be appropriate for the audience being addressed. A more detailed discussion of potential approaches to presenting the evaluation results is provided in Chapter 5.

Objectivity/Third Party Evaluations

It is important to ensure that the results of the evaluation are not biased intentionally or unintentionally. Thus, it is suggested that evaluations be conducted by neutral, unbiased, third parties. While it is critical that the sponsoring agencies, both transit and highway, are actively involved in conducting the study, there is much to be gained by maintaining an outside perspective during the evaluation.

III. HOV FACILITY EVALUATIONS - SUMMARY OF EXISTING PRACTICES

Development of HOV Facilities and Evaluation Programs

The first freeway HOV lanes in the United States were implemented in the late 1960's and early 1970's. The initial section of the Shirley Highway exclusive bus lanes opened in 1969. This was followed in 1971 by the exclusive bus lane approach to the Lincoln Tunnel on Route 495 in New Jersey and the first phase of the Los Angeles San Bernardino Freeway HOV lane in 1973. Since the late 1970's, the use of HOV lanes has expanded greatly. As of April, 1990 there was a total of approximately 40 HOV facilities in operation on either freeways or in separate rights-of-way in 20 metropolitan areas in North America. These facilities vary greatly in terms of the specific HOV application, design, operating characteristics, and utilization rates. An examination of existing HOV projects has been conducted as one element of the UMTA sponsored assessment, and the results are presented in a separate report.[1]

The reasons for implementing HOV facilities and the approaches utilized vary greatly. Many of the HOV applications have been attempts at relatively low cost methods for increasing the capacity of overcrowded freeways. This is especially true of some of the early facilities, which may have been implemented as part of Transportation System Management (TSM) programs. Approaches utilized in these cases include restriping to add an HOV lane to an existing facility, utilizing the shoulder for an HOV lane, and other relatively low cost treatments. Other HOV facilities represent permanent, long-term improvements. These include the construction of higher cost projects, such as bus-only facilities on separate rights-of-way and exclusive HOV facilities on freeways.

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[1]Katherine F. Turnbull and James W. Hanks, Jr. *A Description of High-Occupancy Vehicle Facilities in North America.* Prepared for the Texas State Department of Highways and Public Transportation and the Urban Mass Transportation Administration, Technical Report 0925-1, by the Texas Transportation Institute, July, 1990.

Evaluation methods and approaches have also varied greatly among HOV projects. Given limited resources, the collection of adequate before-and-after data has not always been conducted. In some cases, an initial evaluation may have been completed shortly after implementation, but little or no on-going data collection or evaluation activities were conducted. Thus, evaluating the effectiveness of many facilities has been difficult. In addition, the purpose, or goal, of the HOV facility has not always been well defined. Furthermore, the measures utilized, along with the data collection techniques and evaluation criteria, have differed between areas. Thus, no standard approach or set of evaluation measures, criteria, and data collection techniques exist for evaluating freeway HOV projects.

It should be noted that the lack of common evaluation measures and extensive before-and-after studies is not unique to HOV projects. Many transportation improvements, both highway and transit, have been implemented without a clear articulation of the goals for the project and a definition of the evaluation measures that will be used to determine their effectiveness. Good before-and-after studies are not all that common with highway or transit projects. However, these shortcomings do not dismiss the need for accurate evaluations of the effectiveness of HOV facilities, particularly since many are relatively new projects that are beginning to generate considerable attention. As transportation projects requiring the expenditure of public funds, HOV lanes need to be evaluated to ensure that these investments are providing the expected benefits.

In order to identify past and current practices used to evaluate HOV facilities, a literature review was conducted. A wide variety of reports and articles was examined from numerous sources. These included documents from federal agencies, such as the Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (UMTA), state departments of transportation, local transit agencies, metropolitan planning organizations, consulting firms, university transportation research organizations, and other groups. These reports cover a wide spectrum of topics, including general guidelines for HOV project planning and development, project-specific case studies, and overviews of HOV projects around the country.

Reports dealing with before-and-after project evaluations were examined in more detail. In addition, a limited number of telephone conversations were held with representatives from agencies responsible for different aspects of the evaluations to obtain further information or clarify certain points. The results of this review are summarized in the next two sections. An overall summary of the literature review is presented first. This summary is followed by a more detailed discussion of a few examples of evaluation programs utilized with different HOV facilities.

Literature Review Summary

Since the initial application of HOV facilities in the early 1970's, there has been a steady stream of reports and studies on the subject. These can generally be divided into three categories: 1) reports on planning and evaluation procedures and methods for all types of transportation facilities, including HOV lanes[2]; 2) general reports on the use of HOV facilities, travel demand management (TDM) strategies, transportation systems management (TSM) techniques, and transit; and 3) reports addressing specific HOV projects. The analysis conducted in this assessment focused mainly on HOV project-specific reports. A complete listing of the literature examined during the review is provided in the bibliography.

While the focus of this report and the literature review is on before-and-after evaluations, it is important to note that the evaluation of an HOV alternative is often conducted as part of a detailed corridor planning study. As such, it may represent one of a number of alternatives

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[2]A number of reports documenting planning and demand estimation techniques for HOV facilities are available. The following two reports provide examples of this. Thomas E. Parody. *Predicting Travel Volumes for HOV Priority Techniques: User's Guide*. Prepared for the Federal Highway Administration by Charles River Associates Incorporated, 1982. John M. Mounce, Robert W. Stokes, H. Gene Hawkins, and H. Stephen Payne. *Revised Manual for Planning, Designing, and Operating Transitway Facilities in Texas*. Prepared for the Texas State Department of Highways and Public Transportation by the Texas Transportation Institute, 1988.

under consideration. The results of such an analysis often form the basis for the before-and-after evaluation study if the HOV option is selected as the recommended alternative.

The state-of-the-art review did identify a limited number of evaluations conducted on specific HOV projects. Evaluation reports from Washington D.C./Northern Virginia, Los Angeles, Houston, Seattle, Minneapolis, Orange County, Santa Clara County, and New Jersey were examined. While it is realized that this may not include all of the evaluation studies conducted of HOV facilities, it does, however, represent a sample of the types of studies, level of detail, and approaches that have been utilized with different freeway HOV facilities. It is important to note that the facilities covered in these evaluations represent a relatively small percentage of the approximately 40 HOV projects currently in operation. Formal evaluations have not been conducted on many HOV facilities, and in some areas, the information needed for such evaluations has not been, and is not now being, collected. The following general conclusions appear appropriate based on review of available literature addressing HOV project evaluations.

- Formal evaluations of HOV facilities have been more extensive and comprehensive with major facilities and those with significant federal funding, than lower cost TSM types of HOV facilities. Most of the HOV projects reviewed represented significant investments in major facilities. Many of these, although not all, also included federal funding for not only the facility, but the evaluation and data collection activities as well. The limited number of evaluations on other facilities appears to be due in part to the nature of these facilities, many of which were implemented as TSM activities, and the limited availability of funding for data collection and evaluation efforts.

- While formal evaluations have often been conducted during the initial demonstration stages of some projects, such as the Shirley Highway HOV lanes and the San Bernardino Freeway Busway, ongoing monitoring and evaluation efforts are less common. In this regard, the ongoing data collection and evaluation process used on the Houston HOV lanes appears to represent the most extensive and comprehensive effort currently being conducted.

- Many HOV facilities have been implemented without clearly defining the goals and objectives of the project. This lack of a clear understanding of the purpose and goal of the project makes evaluating the effectiveness difficult, since there is no way of knowing if the goal has been reached when the goal has not been defined. Compounding this problem in some cases is the use of objectives that either cannot be measured or are inappropriate.

- Many evaluations have been conducted using very general evaluation criteria. These measures may be as simple as a statement that the HOV lane should reduce travel times for bus and automobile commuters, without identifying the level of time savings that should occur. Thus, no benchmark or specific threshold is identified against which the project can be measured. If the HOV facility leads to any improvement in the general evaluation measure, the project is considered successful. For example, the Shirley Highway Express-Bus-On Freeway Demonstration evaluation did not set specific improvement levels, but rather used terms like "improve" and "increase". The I-394 and Route 55 evaluation programs represent two of the better examples of the use of specific threshold levels to measure the performance of HOV facilities.

- There does not appear to be a consensus among transportation professionals on which criteria or measures should be used to evaluate HOV facilities. A variety of measures have been used with different facilities. While common elements exist, many different approaches are currently being used. Further, a consensus does not appear to exist on what levels of improvement or change are of sufficient magnitude to conclude that a project has been effective. These appear to be greatly influenced by the type of facility and local conditions and perceptions.

- Some evaluation studies focus just on the HOV lane, without considering the full range of impacts on other elements of the transportation system, such as the effect on non-users in the general purpose lanes and the operation of the total freeway facility. Thus, the full range of impacts are not always considered. Most of the evaluation studies examined in this review took into account some aspects of the non-HOV lanes and the operation of the total facility. It appears that there is agreement that these impacts need to be evaluated, but due to cost limitations, they are not always examined as extensively as might be desired.

- It appears that a statistically valid study design has often not been used with before-and-after studies. As a result, conclusions drawn from data may not be statistically meaningful. In addition, to maximize resources, some areas may try to organize data collection activities to serve more than one purpose. This may reduce the overall effectiveness of the data collection effort and may not provide the information needed to evaluate the HOV facility.

- Many evaluations are based on somewhat limited data that may preclude statistical analysis of the significance of any changes. In many cases, "before" data is very scarce or nonexistent. This, combined with limited samples of "after" data and little ongoing data collection, has often lead to the inability to make meaningful comparisons.

- The evaluation methodology, definition of terms, and data collection methods are often different, making comparisons between projects difficult. A close examination of the data collection methods and definition of terms utilized in the preceding evaluations identified a number of differences. For example, the definition of the length of the peak-period is often different.

- There does not appear to be a consensus among studies on the appropriate way to deal with "outside" changes that may impact the results of the HOV project. These could include such things as the rapid escalation in gasoline prices, or other changes that may impact travel in the area. To monitor these overall changes, some areas monitor and evaluate at least one freeway that does not have an HOV lane to provide a "control" facility for comparison purposes. The Houston evaluation process, which monitors not only the four freeways and HOV lanes, but also two control freeways that do not currently have HOV lanes, provides one of the better approaches for identifying potential outside influences.

- In addition, it appears that a comparison of what the impact would have been if an extra freeway lane was added rather than the HOV facility may be meaningful. Houston appears to be the only area where this type of analysis has been conducted.

Obviously, not all evaluations of HOV facilities suffer from all of these problems. There are examples of good evaluation studies. As discussed in the next section, fairly extensive evaluation studies have been conducted on HOV projects in some areas. However, it appears that there is room for improvement with even the best studies, and all projects would benefit from more standardized procedures for evaluating operating HOV facilities. In addition, to better understand the role HOV projects can play in helping to relieve congestion in metropolitan areas and to advance the state-of-the-art use of evaluation procedures, comparability of data between different projects is highly desirable.

Review of Selected HOV Evaluation Studies

This section examines a number of the more extensive before-and-after evaluation studies that have been conducted on freeway HOV facilities and the approaches that have been utilized in the different metropolitan areas where the facilities are located. Evaluation studies from the following areas are included: Washington, D.C./Northern Virginia; Los Angeles; Houston; Seattle; Minneapolis; Orange County; Santa Clara County; and New Jersey.

The analysis is based on a review of available evaluation reports and additional telephone conversations with representatives from agencies in the different areas. For each location, a brief description is provided of the project, evaluation process, project objectives, evaluation measures and criteria, data collection techniques, and any unique features.

Shirley Highway HOV Lanes, Northern Virginia

The Shirley Highway (I-395) HOV lanes was the first major HOV facility in North America. An initial 5-mile, bus-only lane was opened in 1969. Additional segments of the facility were opened in 1970 and 1971, with the 11-mile, two-lane reversible, barrier- separated HOV facility completed in 1975. Only buses were allowed to use the facility during the initial stages, with vanpools and carpools added later.

A number of evaluation studies have been conducted on the Shirley Highway HOV lanes. The first of these was conducted on the initial Express-Bus-On-Freeway Demonstration project from 1971 to 1975. The demonstration and evaluation were jointly sponsored by the Urban Mass Transportation Administration (UMTA) and the Federal Highway Administration (FHWA). It was conducted by the Technical Analysis Division, National Bureau of Standards, U.S. Department of Commerce. A total of 5 reports were prepared documenting different aspects and time periods of the demonstration.

The initial demonstration project, which was the largest bus and highway project ever sponsored by the Department of Transportation, had three major components. These were the 11 miles of HOV lanes, the use of new-feature buses in express service, and the use of new park-and-ride lots coordinated with the express bus service. According to the final report[3], the

[3]James T. McQueen, David M. Levinsohn, Robert Waksman, and Gerald K. Miller. *Evaluation of the Shirley Highway Express-Bus-On-Freeway Demonstration Project - Final Report.* Prepared for the U.S. Department of Transportation by the Technical Analysis Division, U.S. Department of Commerce, August, 1975.

primary and secondary goals of the project, related objectives, and the evaluation measures are outlined in Table 1.

Specific thresholds, or performance standards, were not set for each of the objectives or measures upon which the project success would be evaluated. Rather, general terms, such as "improve", "increase", and "reduce" were used to describe the desired results.

Extensive data collection and analysis activities were conducted as part of the demonstration evaluation program. These included traffic counts, surveys, and the use of analytical procedures to estimate some impacts. A summary of the major data collection and analysis efforts follows.

- *Vehicular volumes and person trip counts.* Periodic counts were made of peak- period vehicular volumes and person trips (bus and auto) crossing an eight-station screenline that intersected the main radial arterials in the corridor. This information was used to determine overall changes in travel within the corridor, and specifically on the Shirley Highway facility. It was used to analyze changes in the person-movement capacity of the corridor, as measured by changes in total person trips, bus person trips, bus market-share, and auto occupancy rates.

Table 1. Shirley Highway Express-Bus-On-Freeway Demonstration Goals, Objectives, and Measures

Primary Goal: Demonstrate that express bus-on-freeway operations can improve the quality of bus service and lead to an increase in the people moving capability of peak period transportation facilities for the entire urban corridor.

Objectives:

- Increase reliability of bus service
- Reduce travel time for transit and auto commuters
- Increase coverage by bus routes
- Increase bus passenger convenience and comfort
- Increase bus's share of corridor commuters

Measures:

- Operating speed
- Door-to-door travel times
- Reliability of service
- Coverage area of bus service
- Passenger comfort and convenience features (seat availability, fewer transfers, etc.)
- Increase in bus patronage and market share
- Increase in carpooling and reduction in single occupant automobiles
- Growth in person volumes (bus and auto) per lane on the Shirley Highway and resultant changes in the quality of service encountered by both bus and auto commuters.

Secondary Goal: Demonstrate that the technology can have a favorable impact on the transportation-related environmental and social conditions within a corridor and on the economic condition of the transit operator.

Objectives:

- Reduce peak period auto pollutant emissions
- Reduce peak period gasoline consumption
- Increase mobility of the transportation disadvantaged
- Increase productivity of the bus operator

Measures: To determine changes in the social and economic objectives, the following changes were measured:

- Economic Impact - operating costs and capital expenditure, and savings from increased productivity for the bus operators.
- Environmental Impact - gasoline consumption and automobile pollutant emissions.
- Social Impact - use of bus service by transit dependent households.

- *Monitoring bus schedule adherence.* Surveys of bus schedule adherence, as measured by a comparison of the actual arrival time of buses at the first downtown stop with the time listed in the printed schedule, were conducted prior to the opening of the entire busway and at seven times throughout the demonstration.

- *Monthly bus data.* The bus operator provided monthly information on passenger levels, aggregate system costs, revenues, and operating statistics. These were used to evaluate the impact on the transit operator.

- *Bus and auto travel times.* These were measured directly by travel time and speed surveys, and indirectly through asking people's perceptions in the mail-out and passenger surveys.

- *General and specific commuter surveys.* A number of surveys were used to identify changes in commuter behavior, the reasons for these changes and general perceptions. In-depth, mail-back surveys of auto and bus commuters in the corridor were conducted in the initial stage and final stage of the demonstration. Surveys of park-and-ride lot users and bus riders were conducted.

- *Analytical procedures.* Specific analytical procedures were developed to estimate bus market share, commuter travel time savings due to the HOV lanes, bus operating costs, and reductions in automobile volumes, gasoline consumption, and air pollutant emissions.

The final report suggested two additional elements for consideration in future evaluations. First, while the evaluation process for the Shirley Highway Express-Bus-On- Freeway did include surveys of users of the HOV lane and single occupant drivers in the corridor, it did not include any corridor-wide household surveys. This was noted as one weakness of the evaluation in the final report, and it was suggested that this type of survey be included in future evaluations. In addition, the report recommended the development of a better procedure for identifying and analyzing reductions in bus vehicle and driver requirements attributable to the higher speeds on the HOV facility.

Since the initial demonstration program evaluation, which was completed in 1975, there have been a number of other studies that have examined different operational aspects of the Shirley Highway HOV lanes. In addition, some ongoing data collection and monitoring activities have occurred. One of the additional studies was the evaluation conducted during 1985 and 1986 on the legislatively mandated change in the HOV operating hours. The study is worth examining, as it provides an example of a limited before-and-after study conducted to evaluate changes made to an operating HOV facility.

In 1985, federal legislation required a 12-month demonstration changing the HOV operating hours on the Shirley Highway from 24 hours to the peak-periods only (6:00 a.m. to 9:00 a.m. and 3:30 p.m. to 6:00 p.m.). An evaluation of the impact of these changes was conducted for the Virginia Department of Transportation by JHK & Associates. This study focused on a comparison of conditions on the lanes before and after the change in operating hours. The measures of effectiveness used in the analysis are shown in Table 2, followed by a listing of the information utilized in the evaluation.[4]

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[4]JHK & Associates. *The Operation of I-395, Final Report.* Prepared for the Virginia Department of Transportation, July, 1986.

Table 2. Shirley Highway - 12 Month Demonstration, Evaluation Measures of Effectiveness

Category	Measure
Travel Demand	Vehicular Volume Person Volume Modal Share Occupancy Distribution Average Occupancy Vehicle-Miles of Travel Person-Miles of Travel Person Throughput (person-miles/hour)
Quality of Flow	Vehicular Speeds Level of Service
Safety and Environmental	Number, Severity of Accidents Accident Rate (per million vehicle miles and per million person miles) Violation Rate (percent of non-carpoolers during restricted hours) Total Fuel Consumption Total CO, HC, and NO_x Emissions Equivalent Noise Level (L_{eq})

To complete the analysis, the following information was collected and analyzed.

- Traffic counts
  - Automatic traffic volume recorders used on HOV lanes
  - Manual classification counts of automobiles, trucks, and buses
  - Occupancy counts
- Speed and delay runs
- Accidents
- Enforcement citations
- License plate survey

San Bernardino Freeway Busway, Los Angeles

The 11-mile San Bernardino Freeway Busway was opened in 1973. The two-lane, two-direction facility was initially restricted to buses only. Carpools and vanpools were allowed to use the facility starting in 1976. An initial evaluation of the busway was conducted over the first three years of operation, from 1973 to 1976. An additional analysis of the mixed-mode operation was completed in 1978. The evaluations were carried out as a joint effort of the Southern California Association of Governments (SCAG), Urban Mass Transportation Administration, Federal Highway Administration, California Department of Transportation (Caltrans), Southern California Rapid Transit District (SCRTD), and the City of Los Angeles. The evaluations were conducted by Crain & Associates.

According to the final report of the mixed-mode analysis[5], a series of goals and measures of effectiveness were identified for the cost-effectiveness analysis. These are shown in Table 3. The relative importance of these different goals was identified by the busway evaluation committee and the corresponding value was used in the analysis. However, the effectiveness measures did not include the use of specific threshold levels. Rather, like the Shirley Highway evaluation, general terms such as "improve" and "reduce" were used.

[5]Crain and Associates. *San Bernardino Freeway Busway Evaluation of Mixed-Mode Operations*. Prepared for the California Department of Transportation, July, 1978.

Table 3. San Bernardino Freeway Busway Evaluation Goals and Effectiveness Measures

Goal	Effectiveness Measures	Relative Importance
Provide added corridor capacity	Increased carrying capacity of the corridor, in persons per peak hour or period	20%
Reduce environmental impacts of corridor travel	Reduced emissions of air pollutants, in tons per year;	10%
	Energy savings, in BTU-equivalent gallons of gasoline	10%
Improve the level of service	Travel time savings, in minutes per person trip, and the value of such savings, in dollars	20%
Reduce the cost of personal travel	User cost savings, in cents per person trip (including parking cost savings)	20%
Improve the safety of corridor travel	Number of accidents avoided, and the associated dollar savings to society	15%
Provide for future contingencies (e.g., a rail line, future growth, etc.)	Adaptability of the busway for such situations, plus their likelihood and timing	5%

Major elements of the data collection and analysis process included the following.

- *Travel time studies.* Caltrans conducted before-and-after time and speed runs on the busway, freeway, and on several major parallel roadways.

- *Vehicular volume and occupancy counts.* Caltrans also conducted before-and-after vehicle and occupancy counts. This included electronic counts at four locations along the San Bernardino Freeway and one location on the Santa Ana Freeway. Mechanical volume counts were taken at several locations along the busway, at ramps along the Santa Ana Freeway, and on five parallel surface streets. Occupancy counts were taken at one location on the freeway and two on the busway.

- *Violation rates.* Caltrans monitored the number of violators (vehicles using the lane not meeting the occupancy requirements) over the five year period and the California Highway Patrol provided records of enforcement activities.

- *Bus ridership and travel times.* SCRTD provided weekly ridership counts until 1977, after which they were done monthly.

- *Safety.* The California Highway Patrol collected continuous accident data for the busway.

- *User and non-user surveys.* A variety of surveys were used to evaluate user and non-user perceptions of the facility and specific reasons for mode selection and mode shift. These included an on-board survey of bus riders, a handout, mail-back survey of carpoolers and a follow-up telephone survey, a handout, mail back survey of freeway mainlane users, and interviews with bus drivers.

It is interesting to note that the San Bernardino Freeway Busway evaluation contained two elements not included in the initial Shirley Highway HOV facility evaluation. These are the inclusion of safety and accident data, and violation and enforcement data.

Houston HOV Lanes

The first HOV facility in Houston was the I-45 North Freeway Contraflow Lane (CFL) demonstration project, implemented in 1979. The success of this project led to the development of additional HOV facilities, in other freeway corridors. Currently, 47 miles of a planned 97-

mile HOV lane network are in operation; HOV facilities are in operation in 4 freeway corridors. Most of these are one-lane reversible, barrier separated facilities located in the freeway median. A short segment of a two-lane, two-direction HOV facility is in operation in one corridor.

The evaluation procedures, measures of effectiveness, and data collection activities associated with evaluating the effectiveness of the Houston HOV lanes have evolved over the last 11 years. A brief review of the process used with the initial evaluation of the I-45 North Freeway CFL demonstration project and the development of the current procedures is provided here. A more detailed examination of the current data collection activities is presented in Chapter 4.

The I-45 North Freeway Contraflow lane was implemented as an UMTA-funded demonstration program. As such, a fairly extensive before-and-after evaluation was conducted of the facility. The evaluation was conducted by Cambridge Systematics, Inc. TTI assisted with many of the data collection activities. The project objectives and evaluation measures as outlined in the final report, are presented in Table 4.[6]

A variety of data collection activities were conducted to support the evaluation. This included the collection and analysis of traffic and CFL vehicle volume data and a number of surveys of commuters in the corridor. Surveys were conducted of bus passengers, van drivers, van passengers, peak-direction auto drivers and passengers, and off-peak direction drivers. This appears to have been the most extensive use to date of surveys to measure the attitudes and reactions of both users and non-users.

[6]Terry J. Atherton and Ellyn S. Eder. *Houston North Freeway Contraflow Lane Demonstration.* Prepared for the U.S. Department of Transportation by Cambridge Systematics, Inc. December, 1982.

Table 4. I-45 North Freeway Contraflow Lane Demonstration Objectives and Evaluation Measures

Project Objectives:
• Decrease (or slow the growth of) corridor vehicle-miles of travel (VMT) and associated fuel consumption and vehicle emissions
• Increase vehicle occupancy in the corridor
• Reduce congestion and, thus, decrease travel time
• Encourage acceptance and usage of public transportation
Evaluation Measures:
• Person and vehicle utilization
• Characteristics of both contraflow lane users and non-priority travellers
• Impact on non-priority users of the freeway
• Influence in promoting bus and vanpool use relative to other corridor improvements
• Associated safety and enforcement issues
• Public acceptance
• Impacts on corridor VMT, fuel consumption and vehicle emissions
• Associated costs

As other HOV lanes were planned and implemented in Houston, a standardized evaluation program and corresponding monitoring and data collection program began to emerge. The Texas State Department of Highways and Public Transportation (SDHPT) as part of the FHWA HPR program, and the Metropolitan Transit Authority of Harris County (METRO) have sponsored this effort, which has been conducted by the Texas Transportation Institute (TTI). The major elements of this process focus on data collection efforts needed to evaluate the following objectives.[7]

Objectives:

- Increase the effective person-movement capacity of the freeway
- HOV lane implementation should not unduly impact freeway mainlane operation
- The HOV lane project should be cost effective
- Development of the HOV lanes desirably will have public support
- HOV lanes should have favorable impacts on air quality and energy consumption

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[7]Dennis L. Christiansen and Daniel E. Morris. *The Status of the Effectiveness of the Houston Transitway System, 1989.* Prepared for the Texas State Department of Highways and Public Transportation by the Texas Transportation Institute, March, 1990.

Specific levels of improvement have been identified for many of these objectives. To evaluate the HOV lanes based on these general objectives, a variety of information is collected by TTI on a regular basis. The following list provides a summary of the major elements of the ongoing monitoring process. These are discussed more extensively in Chapter 4, as they form the basis for the suggested approach to data collection activities.

- *Vehicle and occupancy counts.* Vehicle and occupancy counts are taken on the HOV lanes and the general-purpose freeway lanes; the same counts are taken on two freeways that do not currently have HOV lanes. These facilities act as a control group. In addition, vehicle and occupancy counts are taken on eight arterial streets that serve as alternative routes to the HOV lane and freeway facilities, and on freeway frontage roads. These counts are taken on a quarterly basis for the freeways and parallel alternative routes, and monthly for the HOV lanes.

- *Park-and-ride lot counts.* Parked vehicle counts are conducted at the park-and-ride lots associated with the HOV lanes and the two control freeway corridors. These counts are taken on a monthly basis.

- *Travel time runs.* Travel time runs are conducted on the four HOV lanes and adjacent freeway mainlanes and the two control freeways on a quarterly basis.

- *User and non-user surveys.* Surveys of bus users, carpoolers, and vanpoolers using the HOV lanes and single occupant vehicles in the general-purpose lanes are conducted on approximately an annual basis. These surveys are designed to obtain information on user's and non-user's perceptions of HOV lane utilization, reasons for mode choice selection, and general attitudes toward the impact of the HOV lanes.

- *Accident data.* Accident data are collected by the Houston Department of Public Safety for the freeway mainlanes and alternative parallel routes, and by Metro for the HOV lanes.

- *Violation rates.* Metro Transit Police monitor the violation rates on the HOV lanes. The vehicle and occupancy counts conducted by TTI also provide a check on violation rates.

The Houston HOV lane evaluation program represents the most extensive and comprehensive ongoing monitoring and evaluation program being conducted of HOV facilities. As such, it represents one of the better models for consideration by other areas.

<u>I-5 HOV Lanes, Seattle</u>

Six miles of concurrent flow HOV lanes were opened on I-5 in Seattle in 1983. A three-month and twenty-month evaluation of the facility were conducted by the Washington State Department of Transportation.[8] The following six general measures of effectiveness were used in the evaluation to determine the impact of the HOV lanes.

- The number of vehicles traveling in the lanes
- The number of people served by the lanes.
- The extent to which people are obeying the laws governing the HOV lanes
- The time savings for freeway commuters
- The affect on the accident rate
- Public reaction

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[8]S.M. Betts, L.N. Jacobson, and T.D. Rickman. *I-5 HOV Lanes: Three Month Report.* Washington State Department of Transportation, December 1983. Washington State Department of Transportation. *I-5 HOV Lanes: A Twenty Month Report.* June, 1985.

No specific thresholds were identified for these measures. It appears that only a limited amount of data were collected for the before-and-after analysis of I-5. Vehicle and occupancy counts were conducted for the HOV lane after two weeks, three months, and twenty months of operation. Freeway mainlane volumes were measured by the average daily traffic (ADT) for the same time period. Violation studies were conducted during the second and third month of operation, and after the implementation of the HERO program, which was initiated in February 1984. Travel-time savings were measured as part of the annual metropolitan travel-time study. Accident information was not available for the three- month study and is not mentioned in the twenty-month study. Public reaction was measured by the number of letters and telephone calls received by the Department.

The ongoing monitoring of HOV facilities in the Seattle area is being conducted as part of the FLOW evaluation process.[9] FLOW is the name given to the transportation system management (TSM) techniques in use in the Seattle metropolitan area. A monitoring and evaluation program of the various elements in the FLOW system is scheduled to continue.

I-394, Minneapolis

An interim HOV lane is currently in operation in the Highway 12/I-394 corridor. The interim facility includes 3 miles of a reversible, barrier-separated HOV lane located in the median of the highway and additional segments of concurrent flow lanes. The final design of I-394, which is scheduled to open in 1993, includes 3 miles of two-lane, reversible, barrier-separated HOV lanes and eight miles of concurrent flow lanes. The interim HOV lane was opened in November 1985.

An extensive before-and-after study of the interim and final HOV lanes was initiated prior to the opening of the interim facility. The evaluation effort is being funded by FHWA and the

[9]Kim C. Henry and Omar Mehyar. *Six-Year Flow Evaluation.* Washington State Department of Transportation, January 1989.

Minnesota Department of Transportation (MN/DOT), and is being conducted by the consulting firm, SRF, Inc. A set of project goals and objectives was identified by the I-394 Project Management Team for both the interim and completed facilities. These formed the basis for the development of the evaluation program.

The development of the evaluation program was completed prior to the opening of the interim facility in 1985. Three different time periods were identified for the project evaluation. These were the construction period, when the interim facility would be in operation, the start-up period for the completed facility, and the stable operating period. The following eight objectives were identified for the HOV facility. Although these objectives were to apply in general to all these evaluation periods, the evaluation program noted that the degree to which they are achieved will vary for each period.[10]

- Increase the peak-hour carpool/vanpool modal split for the I-394 corridor
- Increase the peak-hour transit modal split for the I-394 corridor
- Improve the level-of-service for mixed traffic on I-394
- Maintain or improve the existing level-of-service for mixed traffic on I-394
- Maintain or improve the accident rate along I-394
- Achieve and maintain a low violation rate of the HOV lanes on I-394
- Construct a cost-effective HOV facility on I-394

For each of these objectives, specific performance measures were identified and a corresponding performance threshold was established for each time period. The thresholds were established based on an analysis of the existing conditions and the forecasted use for the different time periods. The performance measures and the thresholds identified for the objective relating to increasing the peak hour mode split are shown in Table 5. This provides an example of the approach and level of detail involved in the I-394 before-and-after evaluation.

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[10]Strgar-Roscoe, Inc. *I-394 Transportation System Management Plan Objectives.* Prepared for the Minnesota Department of Transportation, 1984.

Table 5. Example of I-394 Evaluation Objective and Performance Measures

Objective	Performance Measure	Existing Conditions 1984	Construction Period 1985-1990	Start-Up Period 1991-1992	Stable Operation 1993-2000
Increase the Auto Peak Hour Modal Split	Carpools/Vanpools	625	700	1,075	1,585
	Carpool/Vanpool/ Occupants	1,380	1,540	2,515	4,900
	Carpools as % of Autos	19%	21%	25%	29%
	Carpool Occupants as % of Auto Occupants	34%	36%	42%	56%
	Auto Occupancy Rate	1.23	1.25	1.3	1.6

Source: Strgar-Roscoe, Inc. *I-394 Transportation System Management Plan Objectives*. Prepared for the Minnesota Department of Transportation, 1984.

The I-394 evaluation program is supported by an on-going data collection effort. This program includes many of the same elements as those described previously with other studies. These include regular vehicle and occupancy counts on the HOV lane, mainlanes, and parallel facilities, travel time runs, accident data, violation rates, surveys of users and non-users, and evaluation of the different marketing and public information programs. Like the Houston program, the I-394 evaluation program represents one of the more extensive and comprehensive evaluation programs currently being conducted.

Route 55 Commuter Lanes, Orange County, California

In 1985, 11 miles of concurrent flow HOV lanes were opened on Route 55 in Orange County. Called commuter lanes, this represented the first exclusive carpool facility in Orange County. The lanes were initially opened as part of a 90-day demonstration program sponsored by the Orange County Transportation Commission (OCTC) and the California Department of Transportation (Caltrans). An evaluation program for this demonstration was developed by the Route 55 Advisory Committee. The key issues addressed in the 90-day evaluation are outlined below.[11]

- What is the effect of the commuter lane on overall freeway operations?
  - Is the commuter lane being utilized effectively?
  - What is the effect of the demonstration project on overall freeway utilization?
- What effect has the commuter lane had on travel times and congestion levels in the general use lanes?
- How do the commuter lanes affect overall freeway safety and violations?
  - Are the commuter lanes safe to use?
  - To what extent are freeway users violating the painted buffer and entering and exiting the lanes?

[11]Orange County Transportation Commission and California Department of Transportation. *Route 55 Commuter Lane Demonstration Project: 90 Day Evaluation Report*. February, 1986.

- To what extent are the lanes being used by non-carpoolers?

- Has the commuter lane had an effect on traffic volumes on the parallel arterials and/or freeways?
- What is the public's attitude toward the project?
- Are there any special factors or circumstances that should be reported and considered?

The data collection activities needed to support the evaluation were identified, as were the initial thresholds the project should meet to be considered successful. Data collection activities included vehicle and occupancy counts, travel time and speed runs, accident reports, buffer and vehicle occupancy violations, and monitoring the letters and telephone calls received. Two aspects of the data collection effort are of interest. First, videotaping vehicles at selected locations was used as one method of monitoring vehicle and occupancy counts. Second, no surveys were conducted of users and non-users during the initial demonstration or the first few years of operation. However, in 1987 an extensive Route 55 travel behavior study was conducted that included extensive surveys of both users and non-users of the HOV facility.[12]

Using the same general approach, evaluation studies were conducted on Route 55 after 9 months, 12 months, and 18 months of operation. In addition to the travel behavior study noted previously, additional special studies were conducted oriented toward safety issues. These studies,[13] which were conducted by the Institute of Transportation Studies at the University of California, Irvine, focused specifically on changes in traffic safety resulting from the HOV lanes.

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[12]Sharon Green and Joanna Capelle. *Route 55 Travel Behavior Study, Orange County, California.* Presented at the 68th Transportation Research Board Annual Meeting. Washington, D.C., January, 1989.

[13]Institute of Transportation Studies, University of California, Irvine. *Technical Memoranda 1 and 2, An Analysis of Traffic Safety Relative to the Commuter Lane Projects on SR-55 and SR-91 in Orange and Los Angeles Counties.* Prepared for the Orange County Transportation Commission, Los Angeles County Transportation Commission, and California Department of Transportation, January, 1987 and April, 1987.

Two elements of the Route 55 evaluation process are worth stressing. First, the Route 55 process appears to be the first to use video cameras extensively to obtain vehicle, occupancy, and violation information. Second, and probably more important, the concern over, and emphasis placed on, safety and accident information provides an indication that these elements should be given higher consideration in other evaluations.

Santa Clara County, California, Commuter Lanes

HOV lanes, called commuter lanes, are currently in operation on 3 expressways and 1 freeway in Santa Clara County. These facilities were opened between 1982 and 1988 and represent the first phases of a larger system of HOV lanes. In 1988, the Santa Clara County Transportation Agency engaged the consulting firm of SYSTAN to undertake an assessment of the county's existing commuter lane network. The purpose of the study was to compile and summarize available data on commuter lane usage, travel time savings, safety, and enforcement. This information was utilized to evaluate the effectiveness of the four existing projects.

The final report[14] prepared on the evaluation does not identify any specific goals or objectives the commuter lanes were designed to meet. The evaluation relied primarily on historical data available from Santa Clara County, Caltrans, and other public agencies. The report presents a summary of available data on each facility and identifies additional data collection deficiencies. Based on the available historical data, the following information was examined in the evaluation.

- Vehicle volume counts for both the commuter lanes and the mixed-traffic lanes.
- Occupancy counts for both the commuter lanes and the general-purpose lanes; these counts were used to compute the violation rates and rideshare percentages.

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[14]SYSTAN, Inc. *Commuter Lane Performance Evaluation.* Prepared for the Santa Clara County Transportation Agency, March 1, 1989.

- Travel-time data documenting speed and travel time for vehicles in the commuter lanes and general-purpose lanes.
- Enforcement statistics documenting the number of citations issued for illegal use of the HOV lanes.
- Accident data documenting the number of accidents in the HOV and general purpose lanes.
- Surveys of drivers on routes with commuter lanes.

This information was used in the evaluation to provide a general summary of the operating trends on the facilities. The results were not measured against any preset benchmark. Rather, the evaluation was descriptive in nature, providing an overall summary of the historical trends.

I-95 HOV Lane, Fort Lee, New Jersey

In 1986, a one-mile concurrent flow HOV lane was implemented on I-95 on the eastbound approach to the George Washington Bridge in the Fort Lee, New Jersey/New York City area. A one year operational report was prepared by the New Jersey Department of Transportation.[15] A variety of operational data were collected during the morning peak-period (6:30 a.m. - 10:00 a.m.) on a regular basis throughout the first year of operation. Data collected included vehicle and vehicle occupancy counts, motorcycle use, and auto and bus volumes at the toll plaza.

The results of the data collection activities were used to determine the person-movement efficiency of the facility, motorcycle use, violation rates and enforcement issues, and other

[15]John C. Powers. *George Washington Bridge Bus-Carpool Lane One Year Operational Report.* Presented at the 68th Annual Meeting of the Transportation Research Board, January 1989.

operating characteristics of the facility. Based on the evaluation, the *One Year Operational Report* concludes that the HOV lane has achieved its operating goals.

Summary

The preceding studies represent examples of before-and-after evaluations of freeway HOV facilities. However, as noted previously, these studies represent a relatively small percentage of the approximately 40 HOV projects currently in operation. Given the differences in approaches, objectives, measures of effectiveness, data collection techniques, and definition of terms among these studies, it appears that all areas could benefit from a more standardized approach. Further supporting the need for a more uniform approach to evaluating HOV projects is the programmed implementation of some 30 new HOV facilities by the year 2000. These new projects, combined with planned extensions to existing facilities, could bring the total number of operating freeway HOV projects to 70; accounting for approximately 875 miles of HOV lanes by the year 2000.

To provide assistance to agencies initiating before-and-after evaluations with new HOV facilities, and to provide additional guidance to agencies responsible for monitoring existing HOV projects, a suggested approach for evaluating freeway HOV facilities is presented in the next chapter. The suggested approach builds on the strengths and lessons learned from studies reviewed in this chapter. As such, it is intended to provide a comprehensive approach to evaluating freeway HOV facilities that is appropriate for all types of projects in all types of settings.

IV. THE OVERALL APPROACH FOR EVALUATING FREEWAY HOV FACILITIES

The examination of evaluation studies completed in Chapter 3 provides a base for the development of suggested approaches and procedures for evaluating freeway HOV facilities. The suggested procedures, as outlined in this chapter, build on the strengths of these studies. The approach and procedures are presented to provide guidance to agencies developing before-and-after evaluation programs for HOV facilities. It is realized that individual evaluation programs need to be tailored to the scope of the specific project, special issues of concern, and staff and financial resources available in each area. The suggested approach provides the flexibility to address local concerns and available resources while at the same time providing a comprehensive and more standardized process. The utilization of a more uniform approach should enhance both the quality and comparability of evaluations of HOV facilities throughout the country.

While limitations on staff and financial resources are concerns in most areas, undertaking before-and-after evaluations of HOV facilities should not be taken lightly. A lack of commitment and allocation of adequate resources can negate the value of the resulting study. An insufficient evaluation may be worse than no evaluation at all, as it may lead to erroneous conclusions and inappropriate decisions. The general approach suggested in this chapter provides a framework for conducting before-and-after evaluations. However, in actual practice, the quality of these evaluations will be closely correlated to the time and resources committed to the study.

This chapter outlines a general approach suggested for designing and conducting evaluations of freeway HOV facilities. The overall steps to be followed in the evaluation process are discussed first. These are followed by the presentation of suggested objectives, measures of effectiveness, threshold ranges, and data needs that appear to be appropriate for evaluating the effectiveness of HOV facilities. The specific data collection techniques and methodologies needed to conduct the evaluation are discussed in more detail in Chapter 5.

Suggested Approach

The development of a before-and-after evaluation program and on-going monitoring and evaluation process for freeway HOV facilities should include the major activities that would normally be undertaken as part of any evaluation program. The major steps in this process are outlined in this section. To ensure that a comprehensive, well-designed evaluation program is pursued consideration should be given to each of these steps.

Clear Articulation of Project Goals and Objectives

The goals and objectives the HOV project are intended to accomplish should be clearly defined as the first step in developing the evaluation. This is critical, as the remainder of the evaluation program will be designed to obtain and evaluate information that will largely be used to determine if these objectives have been met. The development of measurable objectives is not an easy task, but time spent on this effort will help ensure a focused evaluation.

For purposes of discussion, the term objective will be used to indicate the goal or purpose the HOV facility is designed to meet. The project objectives should be stated clearly and concisely, so that each represents a well-defined and measurable statement. For example, does the desired increase in person-movement efficiency relate to the peak-hour, to the peak-period, or to all times of the day? A commonly used approach in developing measurable objective statements is to ensure that the statement includes the desired end result, the action that will be taken to achieve this result, and the time frame within which the result will occur. General objectives that appear appropriate for use in evaluating HOV facilities are described in the next section and presented in Table 6.

Identification of Measures of Effectiveness

For each objective, the appropriate measure(s) of effectiveness should be identified, along with the desired threshold level of change that will be used to determine if the facility has met the objective. It is important that this activity focus on identifying the measures that most accurately relate to the objectives, and that meaningful threshold levels be established. These measures and thresholds should relate to the key elements identified in the objective statements.

A listing of some of the commonly used measures of effectiveness is presented in the next section and shown in Table 6. A general discussion of possible threshold values for the different measures of effectiveness is also presented. General ranges for the threshold values are provided based on existing experience. These are presented to assist areas in identifying the range within which the desired change could be expected to occur and do not apply to any specific evaluation. They are included to offer some guidance and reflect the general current state-of-the-art.

Identification of Information Needs

This step identifies the information needed for the evaluation process. The data needed to determine if the objectives have been realized must be identified for each measure of effectiveness. The appropriate methods to obtain and evaluate the information must also be identified. It is important to ensure that the same procedures and definitions are used throughout the evaluation to ensure comparability.

The state-of-the-art review of HOV evaluation studies presented in Chapter 3 identified the basic information needs for before-and-after studies. These include vehicle and occupancy counts, travel time and speed information, safety and accident data, violation and enforcement data, and information on the perception of users, non-users, and the general public. Most of this information is desirable for the HOV facility, adjacent freeway lanes, and a control freeway. The control freeway corridor, which represent a corridor without an HOV or other fixed-guideway transit facility, allows for the monitoring of trends and possible confounding variables that may influence travel in the metropolitan area. If resources permit, obtaining similar information for parallel facilities is strongly encouraged. The relationship between objectives, measures of effectiveness, and information needs is summarized in Table 7 and discussed in the next section of this chapter. Data collection techniques that can be used to obtain the information needed to conduct the evaluation are discussed in detail in Chapter 5.

Development of the Study Design

The previous three activities should all be brought together in the development of a study design. The study design should include a listing of the objectives, measures of effectiveness, thresholds, the statistical study design, and data collection needs, locations, and procedures. Funding and staffing resources can then be matched to the scope of this effort. The study design should identify the procedures for the data collection activities, the schedule, the roles and responsibilities of the different agencies, and the methods for compiling and analyzing the data.

Conduct "Before" Data Collection

In this step, data is collected prior to the implementation of the HOV project. This step is critical. If no "before" data are collected, it is very difficult to determine the impact of the HOV facility. Recreating "before" data after the fact is difficult at best. The timing and duration of the "before" data collection activities is important. Ideally, the data collection should take place well before any construction activities that may impact traffic conditions have started. This helps ensure that a true picture of the "before" conditions is recorded. Similarly, the duration of the "before" data collection should be long enough to provide accurate trend data; a single data point is unlikely to accurately reflect before conditions.

Conduct "After" Data Collection and Evaluation

In this step, the "after" data are collected. Usually a number of different evaluation time frames are identified, such as after six months, after one year, after two years, and on an ongoing basis. This long term perspective is important, since many of the significant impacts of successful HOV projects appear to occur 2 to 4 years after implementation. The before-and-after data are then evaluated based on the procedures identified in the study design, and the project effectiveness is assessed. To ensure comparability of data, it is important that the same procedures, techniques, and definitions be used in both the before-and-after data collection and ongoing monitoring activities. The results of such on-going evaluation efforts provide the opportunity to not only evaluate the effectiveness of the facility, but also to identify potential issues associated with the operation of the facility. These problems can then be addressed to ensure the optimum operation of the facility.

Ongoing Monitoring and Evaluation

After the initial evaluation, an on-going monitoring and evaluation process should be maintained. It is realized that different areas will have different resources available for this on-going process. Thus, the program should be designed to ensure that the key information is collected and analyzed within the resources available. Chapter 5 outlines both a desirable and basic level of data collection and monitoring activities.

Following this general approach will result in the development and implementation of a meaningful evaluation process for examining the impact of the HOV facility. While some elements of this approach may vary in different areas, the basic procedures are appropriate for consideration in evaluating freeway HOV facilities.

Suggested Objectives, Measures of Effectiveness, Thresholds, and Data Needs

As noted in Chapter 3, a variety of objectives, both quantitative and qualitative, have been used to evaluate HOV facilities. The first step in developing an evaluation program is to clearly define the project objectives. The following general objectives represent some of those most commonly associated with HOV facilities.

- The HOV facility should improve the capability of a congested freeway corridor to move more people by increasing the number of persons per vehicle.
- The HOV facility should increase the operating efficiency of bus service in the freeway corridor.
- The HOV facility should provide travel time savings and a more reliable trip time to high-occupancy vehicles utilizing the facility.
- The HOV facility should provide favorable impacts on air quality and energy consumption.
- The HOV facility should not unduly impact the operation of the freeway general-purpose mainlanes.
- The HOV facility should increase the per lane efficiency of the total freeway facility.

- The HOV facility should be safe and should not unduly impact the safety of the freeway general-purpose mainlanes.
- The HOV facility should have public support.
- The HOV facility should be a cost-effective transportation improvement.

These statements represent general objectives that reflect the reasons most commonly cited for developing HOV facilities. These objectives should be defined in more detail and expanded as necessary so that each represents a measurable statement appropriate to the specific HOV project. Once the objectives have been clearly defined, the next step is to identify the appropriate measures of effectiveness (MOEs) that correspond to each objective. These measures should focus on the key elements of the objectives, so that the information needed to determine if the objective has been achieved can be obtained.

Commonly used measures of effectiveness associated with each of the objectives were examined to identify those that appear to represent key elements to be measured. The MOEs that can assist in determining the impact of the HOV facility are included in the following listing. Each of the general objectives is presented, along with possible corresponding measures of effectiveness, threshold guidelines, and data needs. The threshold ranges presented are intended to serve as very general guidelines. It is realized that the appropriate thresholds will vary for individual projects depending on local conditions. These elements are summarized in Tables 6 and 7 provided at the end of the chapter.

Objective: *The HOV facility should improve the capability of a congested freeway corridor to move more people by increasing the number of persons per vehicle.*

Measures of Effectiveness: In general, the increase in the peak-hour, peak-direction person volume resulting from the HOV facility should at least be greater than the percentage increase in directional lanes added to the roadway. In effect this will be accomplished by increasing the average vehicle occupancy (persons per vehicle) on the roadway. A significant portion of the increase in average vehicle occupancy should be the result of creating new carpoolers and new bus riders, rather than just diverting buses, carpools, and vanpools from the adjacent freeway lanes or parallel routes to the HOV facility. The attraction of a significant volume of new bus and carpool users is critical to the effectiveness of HOV facilities. Simply moving existing rideshare patrons from the general-purpose lanes or parallel routes will not impact the person-movement capability of the total corridor.

Specific MOEs that may be appropriate for use with this objective include the following.

- Actual and percent increase in the person-movement efficiency on the total freeway facility (general-purpose lanes plus HOV facility).
- Actual and percent increase in the average vehicle occupancy rate for the total freeway facility (general-purpose lanes plus HOV facility).
- Actual and percent increase in carpools and vanpools for the total freeway facility (general-purpose lanes plus HOV facility)
- Actual and percent increase in bus riders for the total freeway facility (general-purpose lanes plus HOV facility)

For each of these MOEs, it may be appropriate to identify a specific criterion for the anticipated change in the peak-hour, peak-period, and the daily total (e.g. the actual and percent increase in bus riders during the peak-hour, peak-period, and daily total).

General Threshold Ranges: Based on experienced, possible threshold ranges for these MOEs could include at least a 10% increase in the peak-hour, peak-direction average vehicle occupancy, an increase in person volumes greater than the increase in directional lanes added to the roadway due to HOV lane implementation, at least a 20% increase in carpoolers, and, depending on the amount of new transit service provided, a 10% to 20% increase in bus riders.

Data Needs: Primary data needs include before-and-after vehicle and vehicle occupancy counts on the HOV lane(s), adjacent freeway, and control freeway. Secondary data needs include before-and-after vehicle and occupancy counts on parallel roadways, and surveys of users of the HOV facility (bus riders, carpoolers, and vanpoolers) and non-users (individuals in the general-purpose lanes).

Objective: *The HOV facility should increase the operating efficiency of bus service in the freeway corridor.*

Measure of Effectiveness: By increasing bus operating speeds and improving service reliability, HOV facilities can increase the vehicle operating efficiency of bus service in the freeway corridor. The following measures of effectiveness can be used with this objective.

- Improvement in vehicle productivity, measured by operating cost per vehicle-mile, operating cost per passenger, operating cost per passenger mile
- Improved bus schedule adherence, measured by on-time performance
- Improved bus safety, measured by a reduction in vehicle accident rates

General Threshold Ranges: Little analysis has been done on the impact HOV facilities have had on bus service productivity, schedule adherence, and safety. Very limited information is available from the Shirley Highway HOV lanes, San Bernardino Busway, and Houston HOV lanes. Experience from these areas indicate that improvements of 5% to 20% in vehicle productivity can be realized with the implementation of HOV facilities, resulting in similar reductions in operating cost per vehicle-mile, operating cost per passenger, and operating cost per passenger mile. On-time schedule adherence can be expected to improve significantly. Experience from a number of areas indicates that the average schedule adherence for buses operating on HOV lanes improves to 95% or better. The state-of-the-art review did not identify any information on bus accidents. However, depending on the design of the facility, a reduction in the bus accident rate could be anticipated.

Data Needs: Data needed for these measures of effectiveness include before-and-after bus service levels, vehicle productivity, on-time performance, number and severity of bus accidents, vehicle operating costs, and changes in labor, fuel, and other costs. On-time performance is usually measured by the number of vehicles arriving at their destination at the scheduled time. On-time performance may be defined differently by different transit systems, but a range from arriving on schedule to 5 minutes behind schedule is often used. It is suggested that the actual arrival times of buses be monitored before-and-after implementation of the HOV facility, as this provides the most accurate picture of changes in on-time performance. In addition, the perception of bus users to changes in bus on-time performance can be measured through the use of on-board ridership surveys.

Objective: *The HOV facility should provide travel time savings and a more reliable trip time to high-occupancy vehicles utilizing the HOV facility.*

Measure of Effectiveness: During the peak-periods, the travel time on the HOV facility should be less than the travel time on the adjacent freeway lanes in the peak-direction of travel. The reliability of the travel time in the HOV lane should also improve from that experienced in the general-purpose lanes in the pre-HOV lane period.

General Threshold Ranges: A general guide that has been used in some areas is that the travel time savings for users of the HOV facility should be approximately one minute per mile for the length of the HOV facility. This guideline further suggests that a minimum total travel time savings of at least 5 to 7 minutes should be realized during the peak-hour. The travel time reliability of vehicles using the HOV facility should improve from the pre-HOV conditions. Both the Shirley Highway HOV lanes and the Houston HOV lanes have shown significant improvements in travel time reliability.

Data Needs: Travel time runs of vehicles in the general-purpose lanes should be conducted before the HOV project is implemented. Travel time runs of vehicles in both the HOV lane(s) and the general-purpose freeway lanes should be conducted on an on-going basis after the HOV facility is open. The travel time runs can also be used to measure the travel time reliability.

Objective: *The HOV facility should have favorable impacts on air quality and energy consumption.*

Measures of Effectiveness: For the total demand being served by the facility, the HOV lane(s) should have more favorable impacts on air quality and energy consumption than would either no improvement at all or the addition of a general purpose lane. The measures most commonly used with this objective are based on calculations or simulation models that use information generated from other objectives. The following MOEs are commonly used with this objective.

- Reductions in emissions
- Reductions in total fuel consumption
- Reduction in the growth of vehicle miles of travel (VMT) and vehicle hours of travel

General Threshold Ranges: The HOV lane(s) should have a more positive impact on air quality and energy consumption than would either no improvement or the addition of a mixed traffic lane. More specific levels can be set for individual projects based on the results of the demand estimation process.

Data Needs: Estimations based on vehicle and occupancy counts, travel time runs, and responses to surveys are used to measure changes in these MOEs. Most simulation models require a good deal of data. Direct monitoring of air quality impacts along the corridor may be appropriate in some cases.

Objective: *The HOV facility should increase the per lane efficiency of the total freeway facility.*

Measures of Effectiveness: This objective can be measured by a comparison of the peak-hour per lane efficiency of the freeway lanes prior to implementation of the HOV project and combined peak-hour per lane efficiency of the freeway lanes and HOV facility after implementation. The "before" measure can be calculated by taking the person volume on the freeway multiplied by the average freeway operating speed. The "after" measure can be calculated by taking person volume on the freeway multiplied by the average freeway operating speed combined with the person volume on the HOV facility and multiplied by the average HOV lane operating speed.

General Threshold Ranges: A 5% - 20% increase in the peak-hour per lane efficiency of the total facility could be expected from an HOV project.

Data Needs: The information obtained from the freeway and HOV lane(s) vehicle and occupancy counts and travel time runs taken before-and-after implementation of the HOV facility are used to calculate the per lane efficiency.

Objective: *The HOV facility should not unduly impact the operation of the freeway mainlanes.*

Measures of Effectiveness: The capacity and operating speeds of the adjacent freeway mainlanes should not be degraded due to the implementation of the HOV facility. This can be measured by a comparison of the level-of-service on the freeway mainlanes before-and-after implementation of the HOV project. As presented next, it is suggested that safety be addressed in a separate objective.

Threshold Ranges: The level-of-service in the mainlanes should not decline due to the implementation of the HOV project.

Data Needs: The information obtained from the freeway and HOV lane(s) vehicle and occupancy counts and travel time runs taken before-and-after implementation of the HOV facility are used to calculate the level-of-service.

Objective: *The HOV facility should be safe and should not unduly impact the safety of the freeway general-purpose mainlanes.*

Measures of Effectiveness: Appropriate MOEs include a before-and-after comparison of the following items.

- Number and severity of accidents for HOV and freeway lanes
- Accident rate per million vehicle-miles or million passenger-miles of travel for HOV and freeway lanes

General Threshold Ranges: It is suggested that the accidents rates should not increase with the implementation of the HOV facility and that the accident rates should be lower on the HOV facility than the freeway general-purpose lanes. However, if implementation of the HOV facility has resulted in the narrowing of the general-purpose lanes or shoulder, or the removal of a shoulder, this may not be a realistic threshold. Thus, it is suggested that this MOE and possible threshold ranges be carefully examined for each project. Given the experience with some of the evaluations of HOV facilities in California, it appears important to monitor not only the freeway lanes and HOV facility, but also a control freeway to determine any overall changes in accident rates in the area. Maintaining the same analysis procedure throughout the evaluation is another lesson from the California experience.

Data Needs: Statistics on the accident rates on the freeway mainlanes should be collected for a representative period of time before the HOV facility is opened. Statistics on the accident rates for both the HOV lane(s) and the freeway mainlanes should then be collected for a representative period of time after the HOV facility is open. Information collected should include the number, type, and severity of the accidents. Continued, ongoing monitoring should also be conducted.

Objective: *The HOV facility should have public support.*

Measures of Effectiveness: Opinion surveys or other techniques should show support for the HOV facility among users, non-users, the general public, and policy makers; a general perception should exist that the facility is adequately utilized. Since these are two different elements, it is suggested that one MOE focus on the perception of utilization of the HOV facility and another MOE focus on the perception of whether it is a good transportation improvement. The violation rates, or the percentage of vehicles using the HOV facility that do not meet the minimum occupancy requirement, can also be used as a MOE for this objective.

General Threshold Ranges: It may be difficult to establish a desired threshold level for this objective. However, a desired level of public acceptance, user acceptance, and non-user acceptance can be identified and measured through the use of surveys. As a general guideline it is suggested that a majority of users and non-users should feel the HOV facility is a good transportation improvement. The perception of the utilization of the facility may be slightly lower, especially for non-users. In addition, performance measures and thresholds could be established related to the number of calls and letters received concerning the facility. Suggested threshold levels for violation rates are less than 10% for exclusive and contraflow lanes and less than 20% for concurrent flow lanes. It is realized that the violation rates relate somewhat to capacity and public support issues, enforcement design, and the level of enforcement.

Data Needs: Data needed to evaluate this objective can be obtained from surveys of users, non-users, focus groups, and the general public, monitoring of calls and letters, newspaper articles, other public reactions relating to the facility, violation rates, and enforcement levels. Much of this information can be gathered through ongoing marketing and public information programs, which usually contain monitoring and evaluation components. Many of the case studies support the importance of marketing and public information programs to educate both the public and policy makers on the purpose and use of the HOV projects.

Objective: *The HOV facility should be a cost-effective transportation improvement.*

Measure of Effectiveness: The measure most commonly used with this objective is the benefit-cost ratio.

General Threshold Ranges. A number of different elements such as travel time savings, operating cost savings, and savings in the cost of congestion can be included as benefits to calculate the benefit-cost ratio of an HOV facility. It is suggested that a basic guideline is that, if an HOV facility has a benefit-cost ratio of greater than one based only on the value of travel time savings by persons using the facility, then the project can be considered cost-effective. It is realized that this is an extremely conservative approach, since the HOV facility should also generate other benefits. However, it provides a relatively easy to understand measure and is based on obtainable information. Some groups have suggested that only the time saved by new HOV users should be used in calculating the benefit-cost ratio.

Data Needs: In order to develop a benefit-cost ratio, the total cost (capital and operating) of the project is needed along with a costing of the benefits. As discussed above, it is suggested that the travel time savings to persons using the facility be used as a primary benefit.

Summary

Following the suggested approach and procedures outlined in this chapter will provide for a comprehensive before-and-after and ongoing evaluation program for freeway HOV facilities. The listing of objectives, measures of effectiveness, threshold ranges, and data needs should provide adequate direction for the development of an evaluation program that meets the needs and resources of individual areas, while helping to provide comparability among different projects. In order to provide further assistance in the development of a comprehensive evaluation program, the next chapter presents an extensive discussion of data collection methodologies and techniques.

Table 6. Suggested Objectives, and Measures of Effectiveness

Objective	Measures of Effectiveness
• The HOV facility should improve the capability of a congested freeway corridor to move more people by increasing the number of persons per vehicle	• Acutal and percent increase in the person movement efficiency • Actual and percent increase in average vehicle occupancy rate • Actual and percent increase in carpools and vanpools • Actual and percent increase in bus riders
• The HOV facility should increase the operating efficiency of bus service in the freeway corridor	• Improvement in vehicle productivity (operating cost per vehicle-mile, operating cost per passenger, operating cost per passenger mile) • Improved bus schedule adherance (on-time performance) • Improved bus safety (accidents rates)
• The HOV facility should provide travel time savings and a more reliable trip time to HOVs utilizing the HOV facility	• The peak-period, peak-direction travel time in the HOV lane(s) should be less than the travel time in adjacent freeway lanes • Increase in travel time reliability for vehicles using HOV lane(s)
• The HOV facility should have favorable impacts on air quality and energy consumption.	• Reduction in emissions • Reduction in total fuel consumption • Reduction in the growth of vehicle miles of travel (VMT) and vehicle hours of travel
• The HOV facility should increase the per lane efficiency of the total freeway facility.	• Improvement in the peak-hour per lane efficiency of the total facility
• The HOV facility should not unduly impact the operation of the freeway mainlanes	• The level of service in the freeway mainlanes should not decline
• The HOV facility should be safe and should not unduly impact the safety of the freeway general-purpose mainlanes	• Number and severity of accidents for HOV and freeway lanes • Accident rate per million vehicle miles of travel • Accident rate per million passenger miles of travel
• The HOV facility should have public support.	• Support for the facility among users, non-users, general public, and policy makers • Violation rates (percent of vehicles not meeting the occupancy requirement)
• The HOV facility should be a cost-effective transportation improvement.	• Benefit-cost ratio

Table 7. Suggested Objectives, Data Collection Efforts, and Measures of Effectiveness for Evaluating HOV Facilities

Objective	Data Collection Efforts: Vehicle and Occupancy Counts		Travel Time Runs		Surveys[1]			Corresponding Measures of Effectiveness (MOE's)[3]
	Freeway[2]	HOV Lane	Freeway[2]	HOV Lane	Freeway	HOV Lane	Other	
Increase vehicle occupancy	*	*			**	**	**[4]	Actual and percent increase in peak-hour, peak-direction person volume; increase in average vehicle occupancy; and modal shift
Bus operating efficiency			*	*			*[5]	Improved vehicle productivity; improved bus schedule adherance; and improved bus safety
Travel time savings			*	*	**	**	**[6]	Amount of travel time saving by HOV users; reliability of trip time for HOV users
Energy and air	*	*	*	*	**	**	**[7]	Reduction in emissions; reduction in energy consumption
Per lane efficiency	*	*	*	*				Increase in peak-hour per lane efficiency of total freeway facility
Freeway operations	*		*		**			Maintain or improve level of service on freeway mainlanes
Safety	**	**					*[8]	Number and severity of accidents; accident rate per million vehicle miles of travel and per million passenger miles of travel
Public support		**			*	*	**[9]	Percent of users, non-users, and general public who approve of HOV facility; violation rates
Cost effective	**	*	*	*				Benefit-cost ratio

* Indicates the top priority data collection efforts needed to evaluate the objectives.
** Indicates data collection efforts which should ideally be conducted, but are not absolutely necessary to evaluate the objectives.

1 Involves periodic use of surveys of HOV users (bus riders, carpoolers, and vanpoolers), non-HOV users in the general traffic lanes, and in some cases, the general public.
2 It is strongly suggested that these data be collected for both the freeway lanes adjacent to the HOV facility and the control freeway.
3 Some, but not necessarily all, of the suggested MOEs associated with gauging the attainment of the objectives are shown.
4 Vehicle and occupancy counts on alternate arterial routes to identify any changes in throughput for the corridor, counts at park-and-ride lots, and vehicle and occupancy counts on a "control" freeway.
5 Before-and-after bus service levels, vehicle productivity, schedule adherence, number and severity of bus accidents, vehicle operating costs, and changes in labor, fuel, and other costs.
6 Monitoring bus on time performance and schedule adherence before-and-after implementation of the HOV lane(s).
7 Monitoring air quality levels along the corridor and use of simulation models to estimate impact.
8 Monitoring freeway accident rates and types before-and-after implementation of the HOV lane(s), as well as obtaining accident rates on the HOV facility.
9 Identifying violation rates for the HOV lane (i.e., those vehicles not meeting the minimum occupancy requirement). Monitor complaints, media, and policy actions.

V. SUGGESTED DATA COLLECTION TECHNIQUES

The previous chapter identified the general types of information needed to evaluate the objectives and measures of effectiveness most commonly associated with HOV facilities. This chapter examines these data needs in more detail. Utilizing the procedures currently employed to evaluate the Houston HOV lanes as a model, as well as examples from other areas of the country, this chapter identifies a set of suggested procedures and techniques for conducting each of the major data collection activities. In addition to the methods used in Houston, the data collection techniques used in Seattle, Los Angeles, Orange County, and Minneapolis-St. Paul are presented as appropriate to describe different approaches.

The specific data collection activities covered include vehicle and occupancy counts, travel time runs, user and non-user surveys, safety and accident information, and violation rates. For each of these, the suggested data collection approach and procedure are presented. In general, these procedures follow those outlined in the Institute of Transportation Engineers *Manual of Traffic Engineering Studies*[16] and the Transportation Research Board *Traffic Data Collection and Analysis: Methods and Procedures.*[17] These references can provide additional guidance on many of the data collection procedures outlined in this chapter.

The chapter also suggests possible data reduction and analysis techniques and outlines the general resources needed to conduct these activities. The chapter concludes with a discussion of some of the major issues associated with data collection activities, such as frequency, scheduling and resources, training, statistical validity of sampling techniques, the use of cameras and other advanced technologies, the standardization of terms, and the identification of a priority

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[16]Institute of Transportation Engineers. *Manual of Traffic Engineering Studies*. Fourth Edition, Arlington, Virginia, 1976.

[17]Transportation Research Board. *Traffic Data Collection and Analysis: Methods and Procedures*. National Cooperative Highway Research Program Synthesis of Highway Practice, 130. Washington, D.C., 1986.

listing of data collection efforts. This is intended to provide guidance for the allocation of limited resources to ensure that key data elements are collected and analyzed.

The use of sound and consistent data collection techniques is critical to ensuring the integrity of the evaluation process. Any conclusions on the effectiveness of the HOV facility are only as sound as the data upon which the evaluation is based. The methodology used to conduct the data collection activities must, therefore, be viewed as an important aspect of the evaluation process.

As noted in Chapter 3, the on-going monitoring and evaluation of the Houston HOV lanes represents one of the most comprehensive data collection efforts associated with HOV facilities in the country. The monitoring and evaluation program is a joint effort of the Texas State Department of Highway and Public Transportation (SDHPT) and the Texas Transportation Institute (TTI). In addition, the Metropolitan Transit Authority of Harris County (Metro) has supported portions of the evaluation activities. The current procedures have evolved from those initiated with the I-45 North Freeway Contraflow Demonstration Project in 1979.

The existing and planned Houston HOV lane system is shown in Figure 1. Data collection activities are conducted in the four freeway corridors with HOV lanes and two freeway corridors that do not currently have HOV facilities. The four freeway corridors with HOV lanes are the Katy Freeway (I-10W), Northwest Freeway (US 290), North Freeway (I-45N), and the Gulf Freeway (I-45S). The two freeway corridors without HOV lanes are the Southwest Freeway (US 59S) and the Eastex Freeway (US 59N). These two facilities provide a "control" group. In addition, parallel alternate routes are also included in some of the data collection activities.

Currently, data collection activities in Houston are conducted on a regular basis. Vehicle and occupancy counts are taken on a quarterly basis for the freeways, and monthly for the HOV lanes. Travel time runs on both facilities are conducted quarterly. User and non-users surveys are generally conducted on at least an annual basis. Accident and violation data are monitored

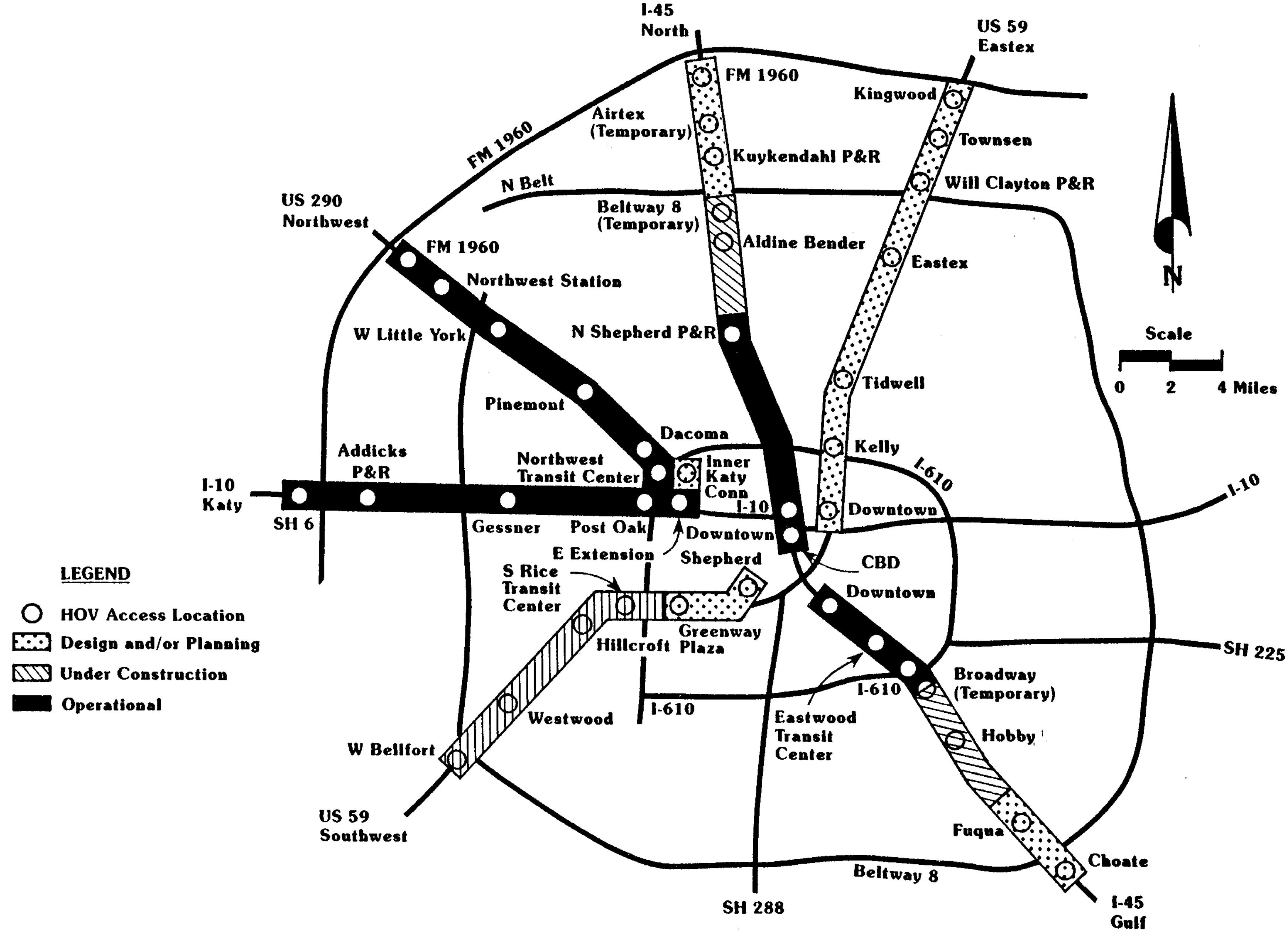


Figure 1. Operational and Proposed Components of the Houston HOV Lane System

on an on-going basis. Each of these data collection elements are described in more detail in the following sections of this chapter. Experiences from other areas of the country are also highlighted to present different approaches.

Vehicle and Occupancy Counts

Vehicle and occupancy counts represent one of the basic data needs for evaluating the effectiveness of HOV facilities. All of the more extensive before-and-after studies reviewed in Chapter 3 utilized some form of vehicle and occupancy counts as the basis for the analysis. These counts measure the number of vehicles and the number of passengers or occupants per vehicle, in both the freeway mainlanes and the HOV facility. Comparing changes in these two variables before-and-after the HOV facility is implemented provides the information needed to evaluate the objectives related to increasing person movement efficiency, cost effectiveness, impacts on energy consumption and air quality, and freeway operations. These are identified in Table 7. In addition, vehicle and occupancy data are critical to evaluating potential changes in occupancy requirements that may be necessary in response to increased demands or legislative action.

Vehicle and occupancy counts are one of the basic data collection activities conducted as part of the ongoing monitoring and evaluation of the Houston HOV lanes. Manual counts are taken on the four freeway corridors with operating HOV lanes and on two freeway corridors that do not currently have HOV lanes. Although HOV lanes are planned for these two facilities, they currently serve as the "control" freeways to monitor general changes in travel and traffic characteristics. In addition, the data currently being collected will provide the base for the before-and-after evaluations of the HOV lanes in these corridors. Counts are also taken along the freeway frontage roads and on parallel alternate routes. Vehicle and occupancy counts are taken on a quarterly basis for the freeway mainlanes, frontage roads, and parallel alternate routes, and monthly for the HOV lanes.

Vehicle and occupancy counts are performed manually during the morning and afternoon peak-periods on the HOV lanes and on the freeway mainlanes in the peak direction. The vehicle and occupancy count locations for the freeways are shown in Figure 2 and the HOV lane count locations are shown in Figure 3. Counts are taken at one location along four of the freeways and at two locations along two freeways. The number of count locations used on the HOV lanes varies from one to three. The count sites were selected based on the ability to clearly and accurately see vehicles in both the morning and afternoon and safety concerns. Since the manual count method relies on human observers in the field, both of these criteria are critically important. The HOV lane and freeway count locations are usually in the same general vicinity. However, due to safety concerns, they are not always at the exact same location. Additional count locations are often used on the HOV lanes to account for the different access points.

At a minimum, at least one count location should be used to collect vehicle and occupancy information for both the HOV lane and the freeway mainlanes. This should be located at the highest HOV volume point if possible. More than one location should be considered if major access/egress points influence the volumes on either facility.

Freeway Vehicle and Occupancy Counts

An example of the location of a freeway count station in Houston is provided in Figure 4. Data are collected in 15-minute intervals. On freeways, vehicle classification and occupancy counts are taken only on the middle or one of the middle lanes. Only vehicle counts and general classification (automobile or commercial) are taken in the other lanes. The occupancy data obtained for the middle lane, with the exception of buses and vanpools, have been shown to provide a reasonable representation of occupancy characteristics for vehicles utilizing the freeway mainlanes in the peak-direction of flow. This reduces the need to collect occupancy data for cars and commercial vehicles on the remaining freeway lanes. However, it is important to note that this methodology has been developed using historical data for the Houston freeway system. The variance of occupancy characteristics across freeway lanes in other urban areas may be different. Therefore, vehicle occupancy data should initially be gathered for each lane.

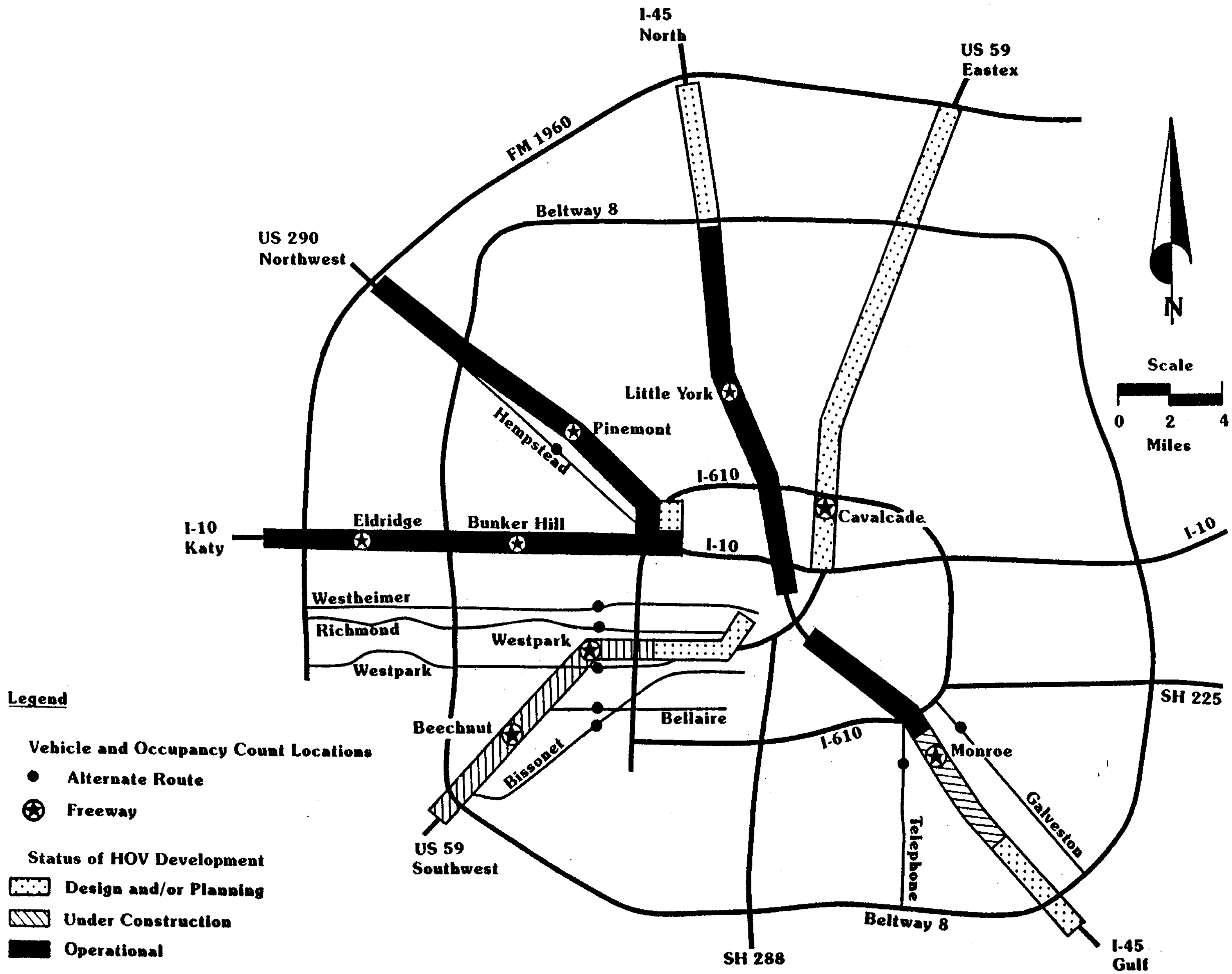


Figure 2. Vehicle and Occupancy Count Locations, Houston Freeways and Alternate Route

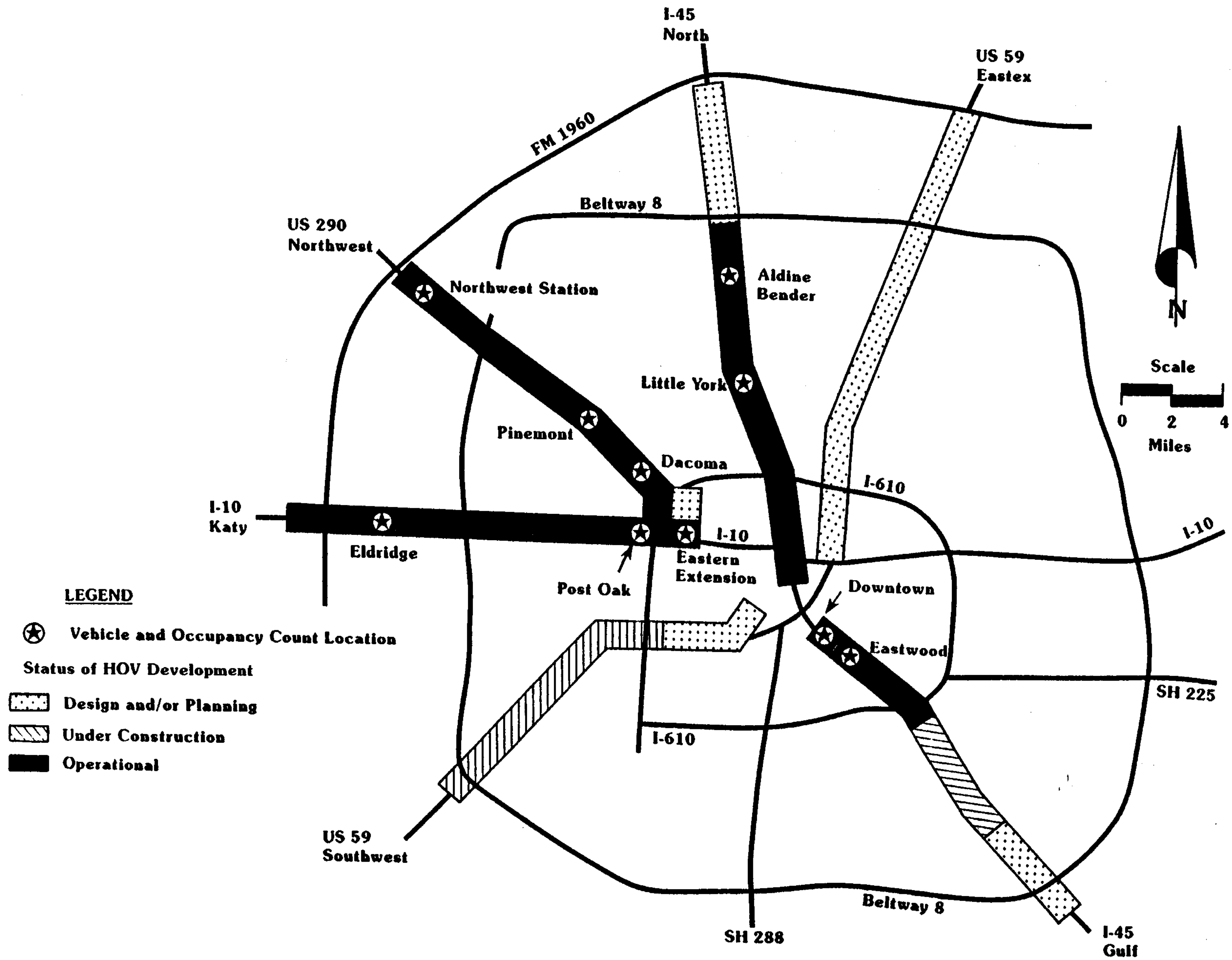
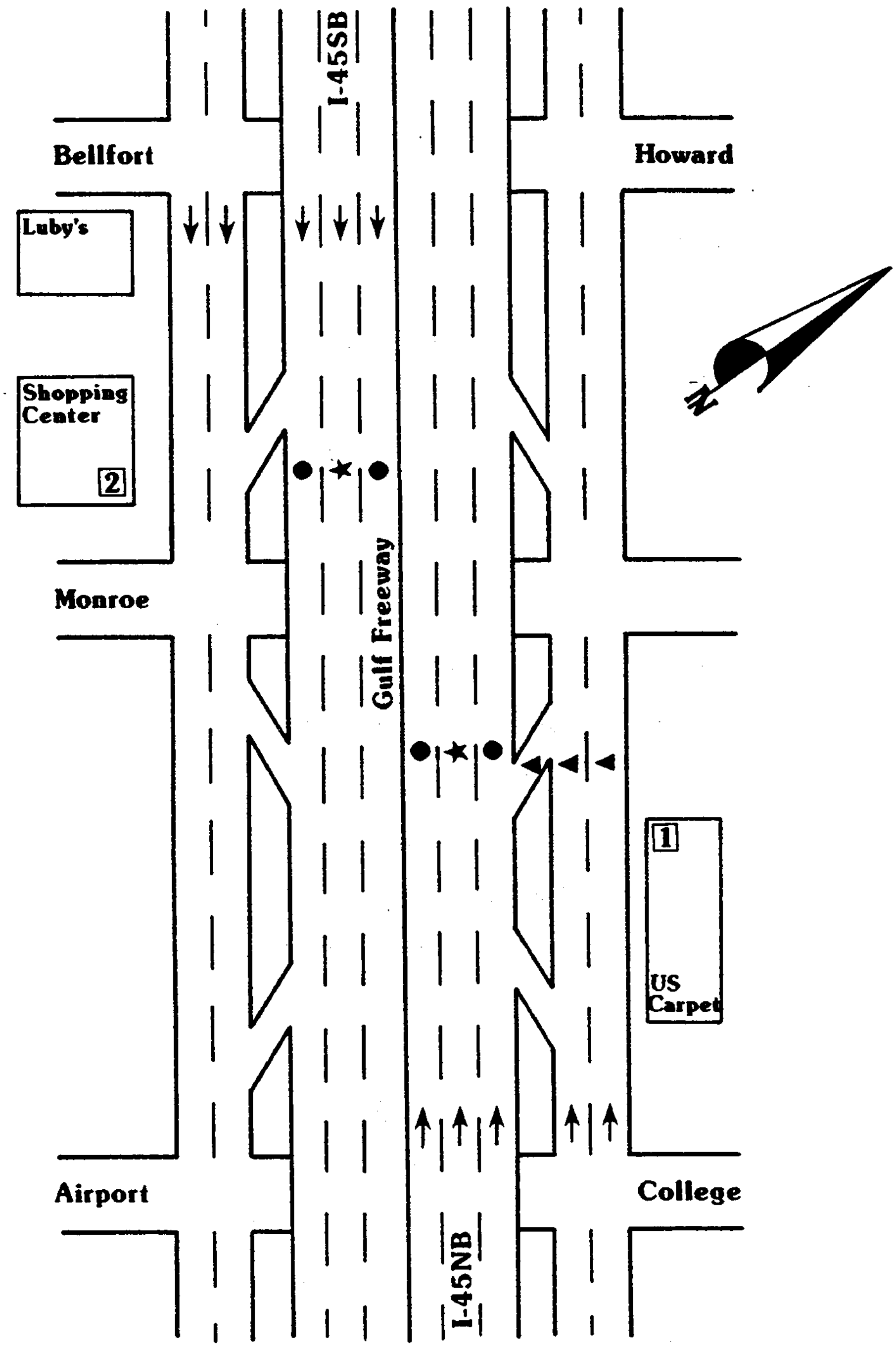


Figure 3. Vehicle and Occupancy Count Locations, Houston HOV Lane System



Legend

[1] **AM Peak Period Count Location**

[2] **PM Peak Period Count Location**

★ **Main Lane Vehicle Classification and Occupancy Count**

● **Main Lane Vehicle Count**

▲ **Frontage Road Vehicle Classification and Occupancy Count**

Figure 4. Map of Gulf Freeway Count Location

If the trends across the lanes are similar, as they are in Houston, counting only one lane may be possible.

The vehicle and occupancy information from the middle lane is recorded on the data sheets shown in Figure 5, while the vehicle and classification information from the other lanes is recorded on the data sheets shown in Figure 6. The occupancy rates observed in the middle lane are then applied to the vehicles in the other lanes to produce the overall person volume estimates for the entire freeway in the peak-direction of flow.

In the Houston analysis, automobiles, pick-up trucks, mini-vans, and motorcycles are classified as cars. Commercial vehicles include taxi cabs, commercial vehicles (delivery trucks, dump trucks, etc.), large emergency vehicles, and large trucks. Since buses and vanpools exhibit occupancy rates that are significantly higher in range and magnitude than those of cars or commercial vehicles, making inferences about the occupancy rates of the other lanes based on those observed in the middle lane could produce serious errors. To reduce this risk, the occupancy rates of buses and vanpools utilizing the other lanes are individually recorded on the data sheet shown in Figure 5.

The observed general bus passenger levels are translated into specific occupancy rates based on the utilization levels identified in Table 8. A person-carrying capacity of 50 persons is used for all standard size buses, including standard Metro buses, school buses, and charter buses, while the capacity of articulated buses is estimated to be 70 persons. Since it is often difficult to observe passenger levels through the tinted bus windows, the accuracy of this procedure is checked periodically by physically counting the number of individuals boarding buses at selected locations. These detailed counts are compared to the survey results, and adjustments to the estimating process are made as needed.

TTI VEHICLE OCCUPANCY DATA

Facility: ______________ **Weather:** ______________
Time: ______________ **Recorder:** ______________
Date: ______________ **Lane:** ______________

Vanpools

1-3	
4-6	
7-9	
10-12	
13+	

Buses

Empty	
1/4 Full	
1/2 Full	
3/4 Full	
Full	
Full+	

Pickups/Passenger Cars

1	
2	
3	
4+	

Commercial

1	
2	
3	
4+	

Motorcycles

Frontage Road Volumes

Trucks 18-Wheelers

1	
2	
3	

Taxi Cabs

1	
2	
3	
4+	

Figure 5. Vehicle Occupancy Data Sheet, Freeway Mainlanes

TTI BY LANE VEHICLE VOLUMES (Freeway)

FACILITY: ____________________ **WEATHER:** ____________________

DATE: ____________________ **RECORDER:** ____________________

Begin Time	Code Time	Lane ______		Lane ______		Lane ______	
		Cars	Commercial	Cars	Commercial	Cars	Commercial
3:30	15						
3:45	16						
4:00	17						
4:15	18						
4:30	19						
4:45	20						
5:00	21						
5:15	22						
5:30	23						
5:45	24						
6:00	25						
6:15	26						
6:30	27						
6:45	28						

Figure 6. Vehicle Volume Data Sheet, Freeway Mainlanes

Table 8. Bus Person Volume Estimates for Different Passenger Utilization Levels

Type of Bus	General Status of Bus Occupancy[1]	Estimated Number of Persons Aboard Bus[2]
Standard Size[3]	Empty	1
	1/4 Full	10
	1/2 Full	20
	3/4 Full	30
	Full	40
	Full +[4]	50
Articulated[5]	Empty	1
	1/4 Full	15
	1/2 Full	30
	3/4 Full	45
	Full	60
	Full +[4]	70

[1] Estimated portion of bus that is occupied by passengers
[2] Corresponding estimate of the number of passengers based on a seating capacity of 40 persons for standard size buses and 60 persons for articulated buses
[3] Includes Metro buses, school buses, and charter buses
[4] Refers to the ultimate capacity of the bus; all seats full and passengers standing in the aisle
[5] Refers to Metro buses that are longer than standard size buses and that have a permanent hinge near the center which allows maneuverability

HOV Lane Vehicle and Occupancy Counts

Manual HOV lane vehicle and occupancy counts are taken during the same time periods as the freeway counts. In addition, HOV lane counts are also taken during the off-peak periods through the use of road tubes. When the Gulf and Katy HOV lanes were opened to weekend use, monthly vehicle and occupancy counts were initiated on Saturdays and Sundays. Due to the high level of importance associated with HOV lane ridership and vehicle volumes, weekday HOV lane data are collected monthly, rather than quarterly. Weekend data are also collected on a monthly basis.

An example of the location of one HOV lane count station is shown in Figure 7. Counts are taken in 15-minute intervals on the HOV lane utilizing the data sheets shown in Figure 8. Vehicles utilizing the HOV lane are classified as carpools, vanpools, and buses. Only full-sized vans are considered to be vanpools, with mini-vans classified as carpools. The same general approach described for the freeway counts is used with the HOV lane counts. The general observed bus passenger levels are translated into specific occupancy rates using the procedure described previously.

Alternate Parallel Routes

Vehicle and occupancy counts are collected at eight locations on alternate parallel routes. The location of these count stations are shown in Figure 2. These counts are conducted to assist in identifying the potential impacts of the HOV lanes on parallel alternate routes. Counts on these facilities are taken on a quarterly basis during the morning peak-period, in the peak-direction of travel. An example of a count station location for a parallel route is shown in Figure 9. The same data collection forms utilized for the middle freeway lane, as shown in Figure 5, are used on these facilities. The same general procedure used for the freeway counts are used on the alternate parallel routes.

Park-and-Ride Lots

Counts of parked vehicles are conducted during the midday at 24 park-and-ride lots in the Houston area. These counts are performed on a monthly basis. The number of vehicles parked at each facility is recorded during the middle of the day on weekdays. The data are currently collected for park-and-ride lots in all four HOV lane corridors, the two corridors in which HOV lanes are planned to operate in the future, and one additional freeway corridor. The data sheet shown in Figure 10 is used to record this information.

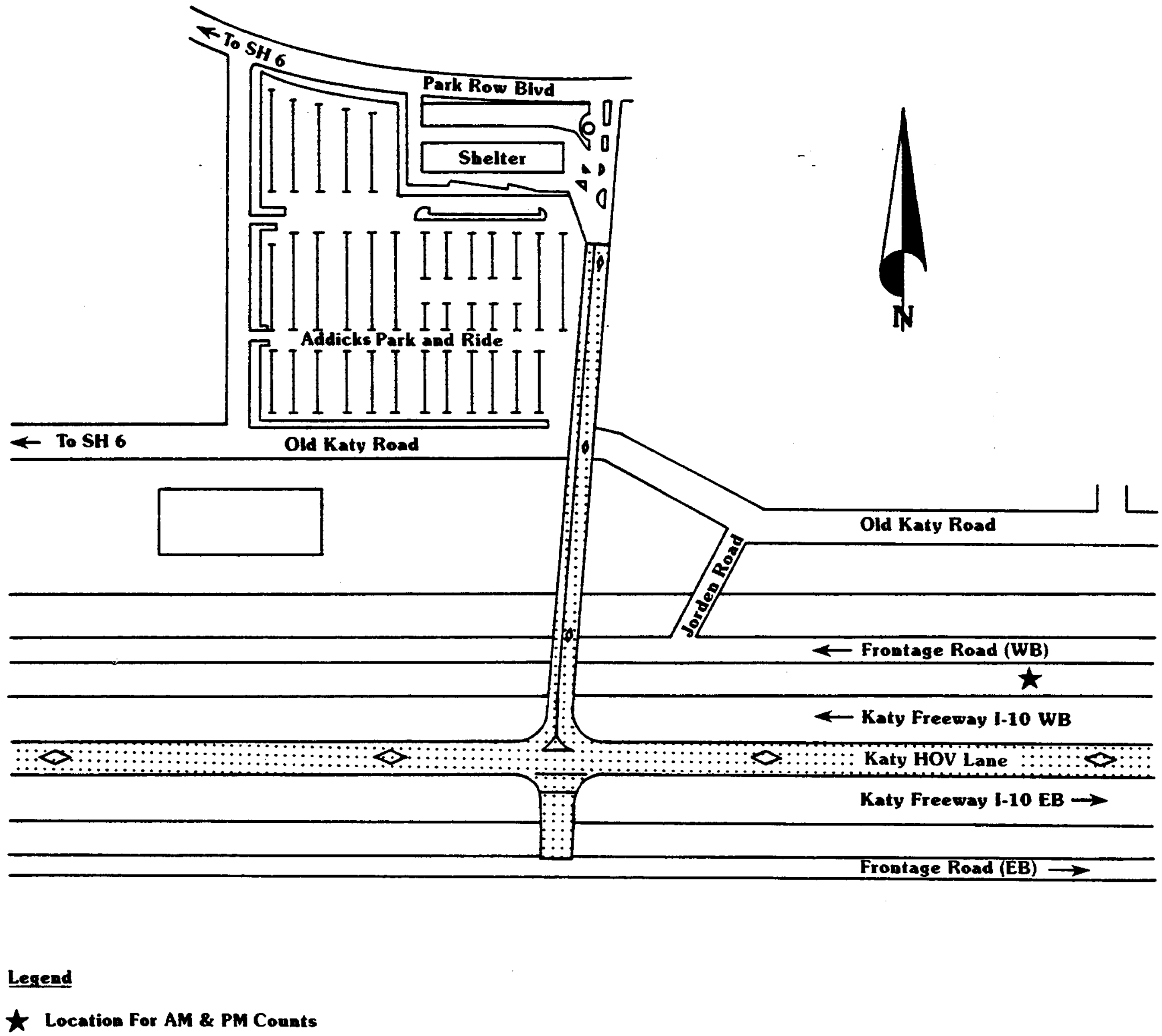


Figure 7. Map of Katy HOV Lane Count Location

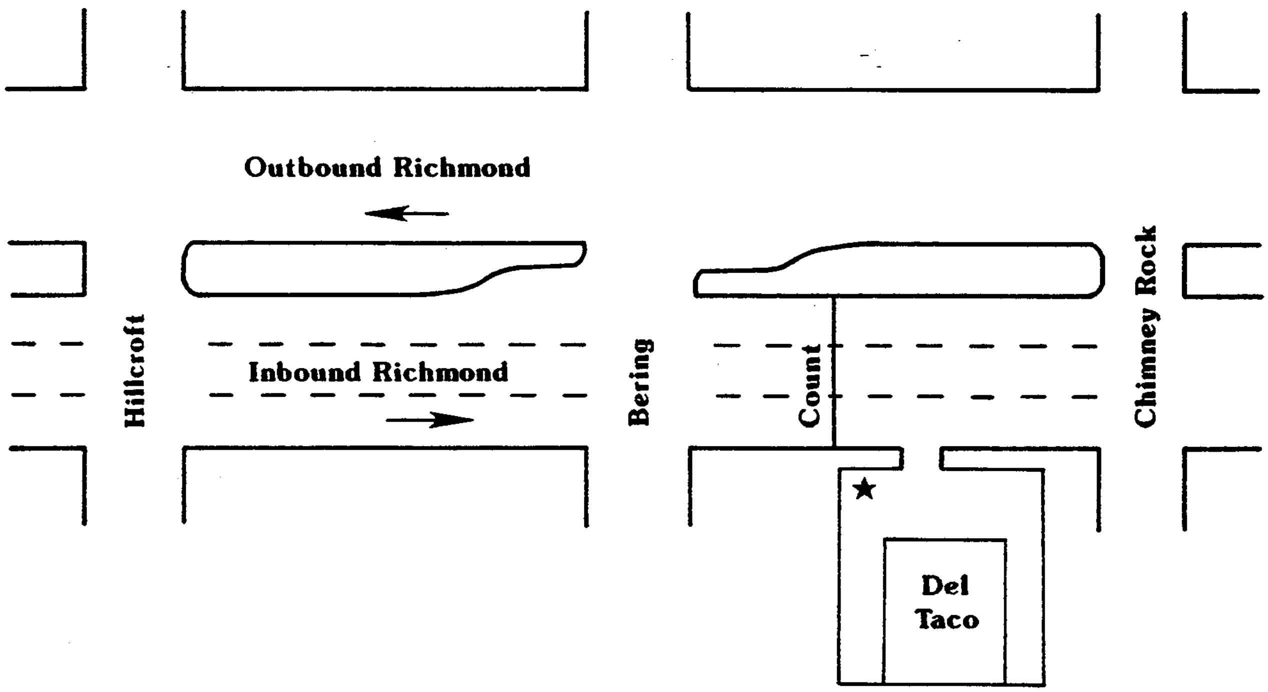
HOV OCCUPANCY SUMMARY

LOCATION: ____________________ **DATE:** ____________

OBSERVER: ____________

TIME	Buses						Vanpools					Carpools				
	E	1/4	1/2	3/4	F	F+	1-3	4-6	7-9	10-12	13+	1	2	3	4	5+
3:30PM																
3:45PM																
4:00PM																
4:15PM																

Figure 8. Vehicle Occupancy and Classification Data Sheet, HOV Lanes



Notes

- **15 Minute Interval Count From 6:00 to 9:30AM**
- **Count Occupancy by Vehicle Types**
- **Do Not Classify by Lane**

Figure 9. Map of Alternate Route Count Location

Month:
Project:

Freeway Corridor	Name of Lot	Number of Parked Vehicles	Date
Katy (I-10W)	1. Kingland		
	2. Fry		
	3. Addicks		
	4. West Belt		
	5. Mason		
	6. Barker-Cypress		
North (I-45N)	1. N Sheperd		
	2. Kuykendahl		
	3. Spring		
	4. Seton Lake		
	5. Woodlands		
Gulf (I-45S)	1. Edgebrook		
	2. Bay Area		
Southwest (US 59S)	1. Sharpstown		
	2. West Loop		
	3. Westwood		
	4. Alief-Boone		
	5. Missouri City		
Eastex (US 59N)	1. Kingwood		
	2. Eastex		
Northwest (US 290N)	1. NW Station		
	2. W Little York		
	3. Pinemont		
I-10E	1. Maxey		

Figure 10. Data Collection Sheet for Park-and-Ride Lot Counts

Other Techniques

As noted, the Houston data collection procedures rely primarily on the use of manual techniques. These are supplemented by the use of road tubes for off-peak HOV lane vehicle counts. This basic approach is commonly used with HOV facilities in many other urban areas. However, some areas have experimented with the use of other techniques or are currently using different approaches. Most of these include the use of some type of technology to assist with different aspects of the data collection process. These approaches and techniques are briefly reviewed in this section.

Some metropolitan areas use closed-circuit television cameras (CCTV), inductance loop detectors, or other devices to obtain vehicle count and classification data. In the Seattle urban area, inductance loop detectors are used to monitor the entire freeway system, including the HOV lanes. In the Minneapolis-St. Paul area, CCTV and loop detectors are utilized on parts of the freeway system and are being incorporated into the new I-394 freeway, including the HOV lanes. This technology will also be implemented in the near future on the freeways, HOV lanes, and parallel alternate routes in Orange County.

Although these technologies are being used successfully to obtain vehicle count and classification data, less positive results have been realized in attempts to obtain vehicle occupancy data through the use of CCTV or other video technologies. Both Orange County and Houston have experimented with the use of video technology to monitor vehicle occupancy rates. The results obtained through these efforts generally were not as accurate as those obtained through manual methods. The primary reasons for the lower degree of accuracy stems from the static limitations of the video technology and the reproductive limitations of the film or television. Thus, the use of these technologies for vehicle counts are often supplemented with manual vehicle occupancy counts.

Advanced technologies are being developed that may overcome some of these limitations. One such device is a video image processing system currently being developed and tested with support from the University of Minnesota Center for Transportation Studies, the Minnesota Department of Transportation, and the Federal Highway Administration. This technology is being designed to collect data such as vehicle counts, vehicle classification, and travel speed.[18]

A research effort sponsored by the Texas State Department of Highways and Public Transportation and conducted by the Texas Transportation Institute has resulted in the development of piezoelectric film, which can be utilized in combination with inductance loop detectors in a weigh-in-motion program to count and classify vehicles. Although to date neither of these technologies have been used with HOV facilities, both may hold promise for future applications.

Travel Time Data

Travel time data represent the second most common type of information needed to evaluate HOV facilities. Travel time data measure the time it takes a vehicle to travel a certain distance. Travel time data are usually collected for the freeway facility prior to implementation of the HOV facility. These same data are then collected for both the HOV facility and the freeway mainlanes after the HOV facility has been opened. The differences in travel times can then be compared for the before-and-after freeway conditions, the before freeway with HOV lane(s), and current freeway with HOV lane(s). In addition, as shown in Table 7, the travel time data are used to help determine the benefit-cost ratio, energy consumption and air quality impacts, and freeway operational impacts.

Travel time data for the freeway and HOV facility can be obtained using a number of methods. The simplest, and most commonly used, is referred to by a variety of names including the "floating car" and "maximum car" techniques. All refer to the use of a test vehicle making a series of trips along a roadway or HOV lane section to obtain travel times. The techniques

[18]Image Sensing Systems. *Information Brochure*. Undated.

are based on the concept that the test vehicle should travel at the average speed of other traffic without exceeding the speed limit.

Travel time data are obtained for the Houston HOV lanes and freeways identified in Figure 1 on a quarterly basis. Travel time runs are conducted during the morning and evening peak-periods in the peak-direction of travel, with the test vehicles dispatched at 30-minute intervals. Two people per vehicle are needed to conduct the travel time runs; one to drive and one to monitor the stop watch and record the results. Ideally, travel time runs should be conducted at the same time on both the HOV facility and freeway lanes. To accomplish this in Houston, it is usually necessary to have between 2 to 4 vehicles making the travel time runs. The exact number of vehicles and corresponding personnel depends on the length of the HOV facility and travel speeds.

Freeway Travel Time Runs

The methodology utilized in Houston to collect the freeway and HOV lane travel time information is the test vehicle method referred to as the "floating car" technique. Figure 11 provides an example of how this process works for both the freeway lanes and the HOV lanes. The specific procedure consists of the driver beginning at a designated starting point with the passenger setting a stopwatch at zero. The driver begins traversing the freeway using the floating car technique, while the observer notes the elapsed time at predetermined mile points on the form shown in Figure 12. If at any time, the traffic flow conditions on the freeway cause the driver to travel at a speed below 35 mph, which is considered to be the upper range of travel speed indicating traffic congestion on freeways, the passenger records the mile point, time at which the vehicle speed was reduced to less than 35 mph, and the apparent cause of the slow-down on the data sheet. Once the test vehicle regains a speed of 35 mph, the mile point and time are again noted. Thus, the length and nature of the traffic congestion problem is recorded.

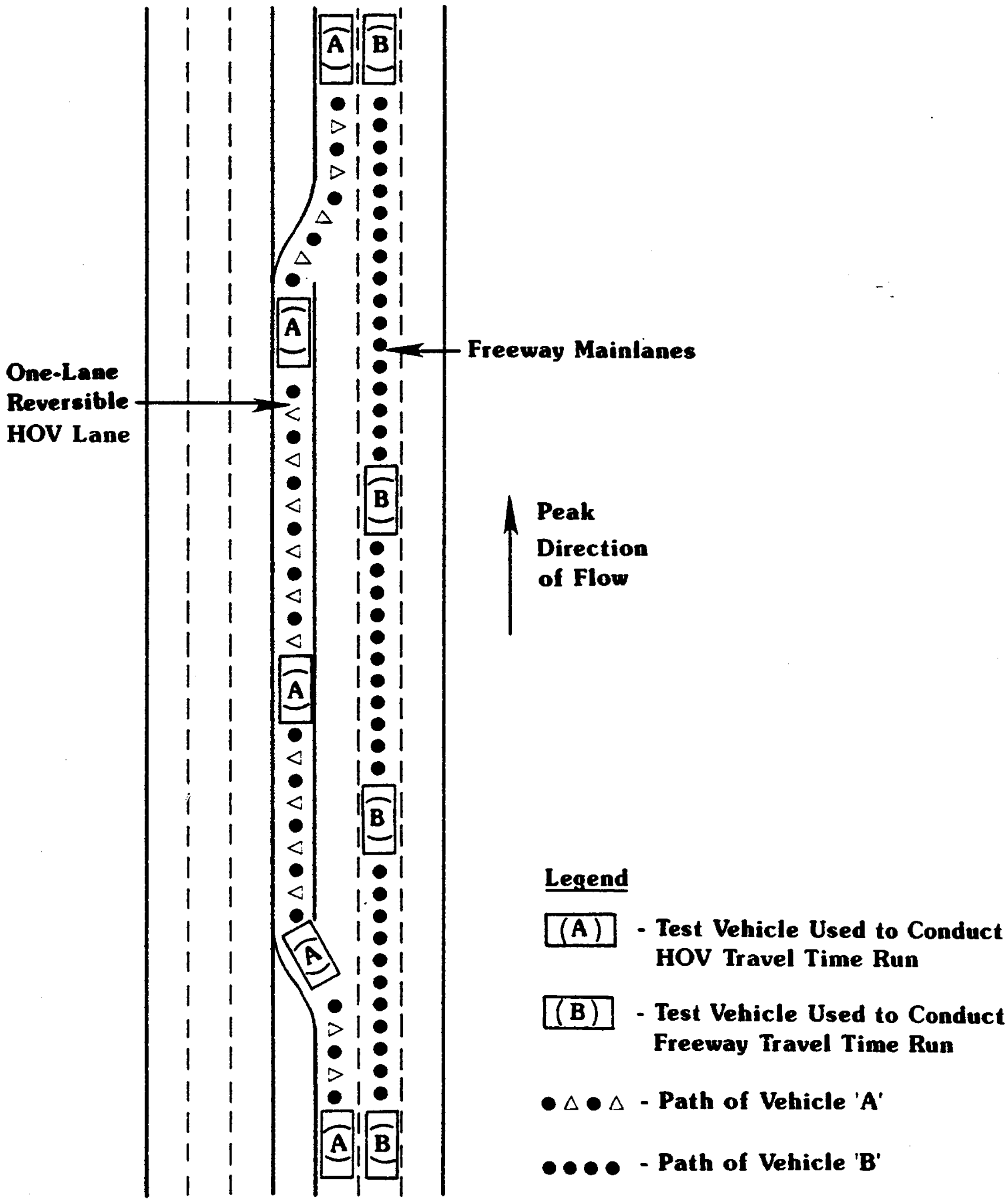


Figure 11. Example of Test Vehicles Conducting Travel Time Runs

Highway: Northwest (US 290) **Run Date:** 6/14/90 **Time Run Start:** 7:30 a.m.

Direction: SB **Mile Run Start:** 946.9

Section Limits	Mile Point	Clock Time	Remarks				Queue		Construct.	
			Weath	Light	Pave	Incid	Mile	Time	Type	Mile
Telge	----	----								
Huffmeister	1.60	1.40								
* FM 1960	0.95	2.38								
Eldridge	1.25	3.57								
Jones Rd.	1.42	5.24								
FM 529	1.20	6.26								
Senate	0.42	6.57								
W. Little York	1.00	8.07								
Gessner	0.45	10.06								
Fairbanks	1.15	12.45								
W. Tidwell	1.05	14.26		Adjacent freeway travel time = 25 minutes and 39 seconds (25.65 minutes)						
Hollister	0.30	14.47								
Pinemont	1.00	16.05								
Bingle	0.30	17.26								
Antoine	1.35	20.33								
W. 34th	0.45	21.21								
Mangum	0.85	25.06								
** I-610 Overpass	0.75	28.17								
SPRR @ I-10	2.20	32.03								
Washington	0.92	32.95								
Shepherd	1.20	34.23								
Taylor	1.70	36.20								
Hogan St.	1.00	37.35								

* Entrance point to HOV lane during morning operations

** Exit point of HOV lane during morning operations

Figure 12. Example of Freeway Transit Time Data Sheet

This procedure represents a modification of the process outlined in the Transportation and Traffic Engineering Handbook[19], but serves to collect the same basic data.

In addition to recording decreases in travel speed below 35 mph, construction zones, weather, lighting and pavement conditions, and incidents are also noted, regardless of whether or not they cause a significant reduction in travel speed. This approach has been used due to the excessive amount of freeway construction that is, and will continue to be, taking place in the Houston urban area.

It is important that when the test vehicle method is used, the entrance and exit points of the HOV lane should be designated as check points for recording the elapsed time. This will ensure that the travel time check points will be the same for both the freeway and the HOV lanes, allowing comparability between results. For example, the travel times for the HOV lanes and freeway lanes, as shown in Figures 12 and 13, can be compared.

HOV Lanes

The same general approach is used for conducting the HOV lane travel time runs, with slight modifications. As shown in Figure 11, the floating car begins at the same designated starting point used in the freeway runs. This point is prior to the entrance to the HOV facility. The passenger starts the stop watch at this point as the vehicle starts along the freeway. The vehicle progresses along the freeway, enters the HOV lane, progresses the length of the HOV lane, and reenters the freeway traffic lanes. Throughout the trip, the passenger records the time at various checkpoints on the data form shown in Figure 13. Since the HOV lanes are one lane, the driver cannot pass or be passed. The drivers are instructed to maintain the travel speed of other vehicles in the lane, but not to exceed the speed limit. As with freeway travel time runs, the passenger records both the duration and reasons for travel speeds falling below 35 mph.

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[19]Institute of Transportation Engineers, *Transportation and Traffic Engineering Handbook.* Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1982.

Highway: Northwest (US 290) **Run Date:** 6/14/90 **Time Run Start:** 7:30 a.m.

Direction: SB **Mile Run Start:** 85.7

Section Limits	Mile Point	Clock Time	Remarks				Queue		Construct.	
			Weath	Light	Pave	Incid	Mile	Time	Type	Mile
Telge	----	----								
Huffmeister	1.60	1.37								
* FM 1960	0.95	2.29								
Eldridge	1.25	3.41								
Jones Rd.	1.42	4.11								
FM 529	1.20	5.06								
Senate	0.42	6.20								
W. Little York	1.00	6.47								
Gessner	0.45	7.53								
Fairbanks	1.15	8.23								
W. Tidwell	1.05	9.32		Transitway travel time = 13 minutes and 27 seconds (13.45 minutes)						
Hollister	0.30	10.37								
Pinemont	1.00	10.59								
Bingle	0.30	11.55								
Antoine	1.35	13.41								
W. 34th	0.45	14.08								
Mangum	0.85	15.02								
** I-610 Overpass	0.75	15.56								
SPRR @ I-10	2.20	18.21								
Washington	0.92	20.20								
Shepherd	1.20	22.36								
Taylor	1.70	24.12								
Hogan St.	1.00	25.24								

* Entrance point to HOV lane during morning operations

** Exit point of HOV lane during morning operations

Figure 13. Example of HOV Lane Travel Time Data Sheet

In addition, information on the travel times of buses using the HOV lanes is also obtained in conjunction with the on-board bus surveys. The personnel distributing the surveys, on the buses, also record the bus travel time information. These surveys are done on an approximately annual basis.

Other Techniques

Another technique for collecting travel time information involves recording license plate and time information at specific points along the freeway and HOV facility. This information can be recorded manually, or as is done in Seattle, recorded into lap-top microcomputers. An example of the use of this method is provided in Figure 14. Individuals stationed at locations "A" and "B" record the license plate data and time for passing vehicles. If lap-top computers are used, the time of the entry is recorded automatically. If the manual method is employed, both the time and the license plate information must be recorded. Depending on the method used, a series of computer programs are used to match the license plates and compute the travel times for vehicles between the two points.

Surveys

A number of the evaluation studies examined in Chapter 2 utilized different types of surveys as one method of attempting to quantifying some of the impacts of HOV facilities. The most commonly used surveys focus on users of the HOV facility, including specially designed questionnaires for carpoolers, vanpoolers, and bus riders, and non-users in the adjacent freeway lanes. In some cases, random surveys of residents in the corridor or metropolitan area, surveys of businesses in the corridor, and special marketing surveys, have also been used.

The use of surveys appears to be one of the best ways to identify the perceptions of users and non-users toward utilization of the HOV facility, changes in mode choice and the reasons for this change, and obtaining socio-economic, demographic, and general travel information on

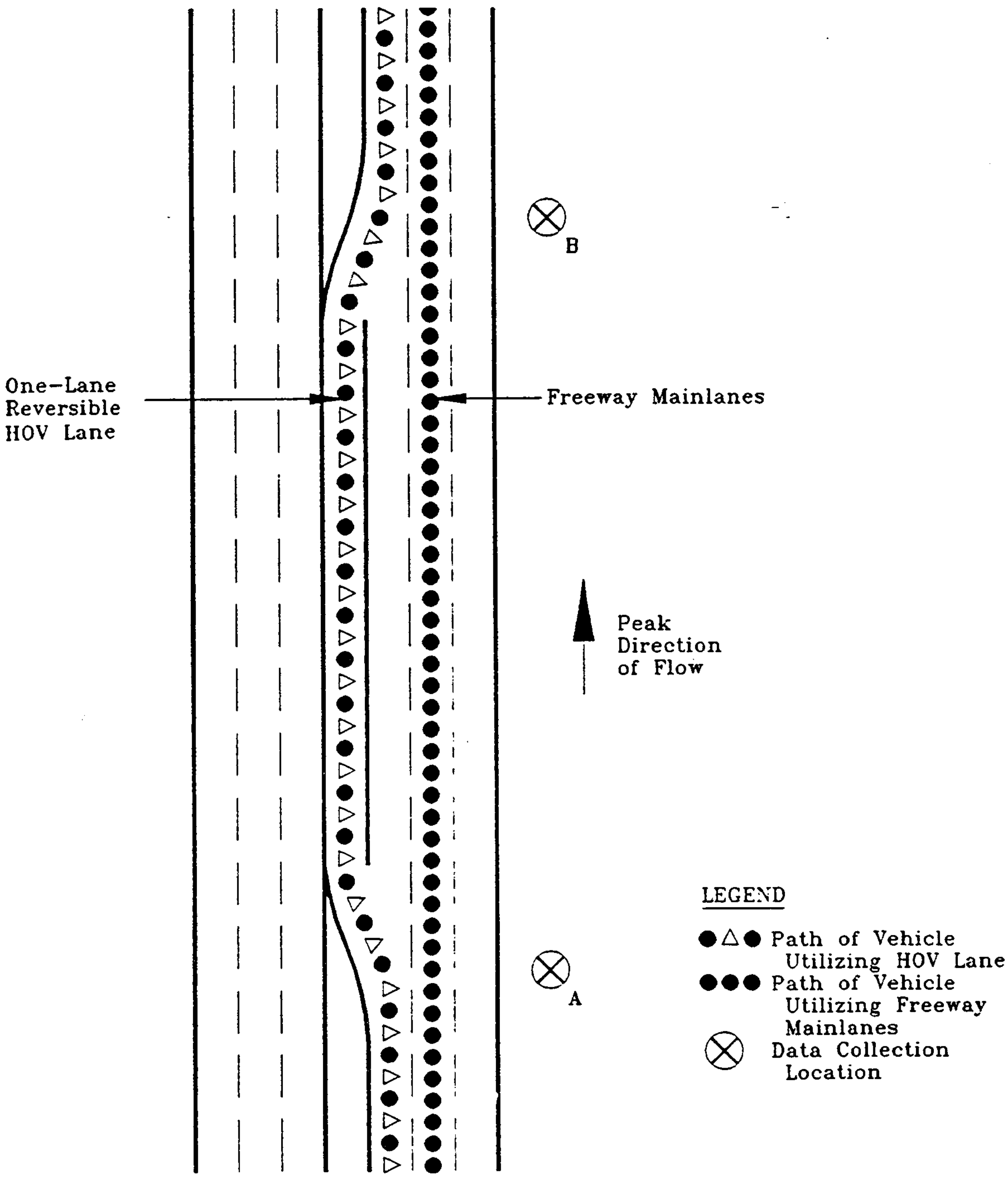

Figure 14. Data Collection Locations for Lap-Top Computer Approach

commuters in the corridor. A better understanding of these elements is important for evaluating many of the HOV project objectives, especially those relating to mode shift and public support.

The methods and procedures used in Houston to conduct surveys of bus riders, carpool and vanpool users, and non-users in the freeway mainlanes are described in this section. The surveys are conducted during the a.m. peak-period on approximately an annual basis. No major differences in the general surveying techniques were identified with other HOV facilities. Thus, the procedures described for Houston appear to represent the standard approach.

On-board Bus Rider Surveys

A copy of a survey that has been used with bus riders on the HOV lanes in Houston is provided in Appendix A. It is designed to obtain information on trip purpose, origin-destination, previous mode of travel, reason for using the bus, the importance of the HOV lane in mode selection, perceived travel time savings from the HOV facility, perception of utilization rates on the HOV lane, and socio-economic characteristics. To maintain a one page format the questionnaire is kept relatively simple, focusing only on key information needs. Since individuals will be completing the survey on the bus, maintaining a simple, easy to complete format is essential. Other survey forms with different questions have been used on occasion for different purposes.

Due to the large volume of park-and-ride and express buses operating on the Houston HOV lanes, a 30% sample of peak-period buses using each HOV lane is utilized. All passengers on these buses are asked to complete a survey. For example, this equates to approximately 25 buses and 1,200 passengers on the Katy HOV lane. In areas that may not have this large a volume of buses using the HOV facility, a larger sample size may be feasible. The appropriate sample size should be selected for each project to ensure that a representative and statistically meaningful survey is conducted. This issue is discussed more extensively later in this chapter. It is also important to obtain a relatively even distribution of bus trips throughout the morning peak-period. In addition, it is important to complete surveys of one park-and-ride facility or express bus route in one day, so that riders are not surveyed twice. Approximately 8 to 12 personnel a day are needed to conduct the bus surveys on one HOV facility in Houston.

In Houston, surveys and pencils are distributed by TTI personnel to all passengers as they board the bus. The completed surveys are then collected by the same personnel as passengers exit the bus. Response rates on the on-board ridership surveys on the HOV lanes have averaged approximately 95% over the past few years. This basic approach is used in most areas, although sometimes slight modifications may be used, such as having the bus driver collect the completed surveys.

Carpool and Vanpool User Surveys

The questionnaire used to obtain information from carpoolers and vanpoolers using the HOV lanes is similar in scope to the bus rider survey. A copy of this survey is provided in Appendix B. However, the methodology used to distribute and collect the survey is different. A mail-out, mail-back format is used.

The procedure starts with TTI personnel recording the license plate numbers of carpools and vanpools using the HOV lanes during the morning peak-period from 6:00 a.m. to 9:30 a.m. The attempt is made to record the numbers from all vehicles in the lane. The numbers are read into a tape recorder, as this has proven to be the fastest and most reliable method. The numbers are then transcribed and sent to the State Department of Highways and Public Transportation (SDHPT), Division of Motor Vehicles. SDHPT provides a listing of addresses from the motor vehicle registration files. Corporate and leasing agency addresses are deleted by TTI, along with those outside the metropolitan area, and surveys are mailed to the remaining addresses with a postage-paid return envelope.

The response rates to the carpool and vanpool surveys in Houston have been good. For example, a total of 2,200 license plates were recorded for the recent survey conducted on the Katy HOV lane. Of these, 1,500 met the above requirements and were sent surveys. The other

700 were either addresses of corporations, leasing agencies or residences well outside the Houston area. Of the 1,500 mailed surveys, 590 completed surveys were returned, accounting for a response rate of 39%.

Instead of recording license plate information and mailing surveys to vanpoolers and carpoolers, some areas have handed surveys directly to the drivers as they are entering or exiting the lanes. The completed surveys are then mailed back in the postage-paid envelope provided. This approach was used in Houston for a period of time. It was discontinued due to the increase in volumes on the HOV lanes and concerns about safety and disrupting the operation of the facility. However, this approach may be appropriate in some areas if the right set of conditions exist.

Non HOV Users in the Freeway General Purpose Lanes

A copy of the questionnaire sent to drivers in the general purpose lanes in Houston is provided in Appendix C. The survey is similar in focus to the bus rider and vanpooler and carpooler surveys. The procedure for administering the survey is similar to that used with the vanpool and carpool surveys. TTI personnel record license plate numbers of vehicles traveling in the mixed-traffic lanes. Surveys are mailed to the appropriate addresses provided by SDHPT, with a postage-paid return envelope. In the most recent survey conducted on the Katy Freeway mainlanes, a total of some 4,800 license plates were recorded. Out of this, approximately 3,100 surveys were mailed. A total of 1,050 completed surveys were returned, accounting for a 37% response rate.

Safety and Accident Information

As noted in Chapter 2, information on the safety and accident impacts of HOV facilities have been important considerations in some areas. Safety and accident information has been an important element of the Houston evaluation process. Safety and accident information is monitored on the HOV lanes, in the adjacent freeway general-purpose lanes, and on the control freeways as part of the on-going evaluation process in Houston. Accident information for the freeways, both those with HOV lanes and the control freeways, is obtained from the SDHPT and the Houston Department of Public Safety. Metro maintains the accident records for the HOV lanes. Thus, TTI has not had to conduct any additional data collection activities related to safety or accidents. The information from the Police Department and Metro is analyzed by TTI and included in the evaluation process.

Similar types of approaches to collecting safety and accident information have been used with other HOV facilities. The needed data are usually obtained from the appropriate agency or jurisdiction. In most cases, this is the state enforcement agency, usually the state police or state highway patrol. However, some cases the local jurisdictional police may also be involved. The experience in California indicates the need to ensure that accident information is recorded as accurately as possible and that the same recording and analysis methods be utilized throughout the course of the project.

Violation Rates

The violation rates, which reflect the number of vehicles not meeting the minimum HOV lane occupancy requirements, can provide a general indication of the degree of public understanding and support for the facility and if the facility is being used for the intended purpose. In Houston, violation rates are monitored in two different ways. First, the Metro Transit Police, which are responsible for enforcement of the HOV lanes, maintain records on the number of citations issued. Second, the vehicle and occupancy counts conducted by TTI also provides information on the number of vehicles, by time of day, not meeting the minimum occupancy requirements. The results from both of these sources are examined by TTI as part of the on-going monitoring and evaluation process.

These two approaches are commonly used with other HOV some areas have experimented with the use of video cameras to monitor occupancy levels and violations of the occupancy requirements. Current technologies appear to have a number of limitations, preventing their use at this time. However, as new technologies are developed, video cameras or other approaches may be appropriate for use in monitoring HOV lane violation rates and related enforcement activities.

Data Reduction and Analysis

The data collected from the Houston vehicle and occupancy counts, travel time runs, user and non user surveys, accident rates, and violation levels are analyzed by TTI staff. The computer program SAS (Statistical Analysis System) is used to manage and analyze the data. This program allows for the maintenance of large data files and the creation of subfiles for specific analysis activities. TTI publishes a quarterly summary of the results of the ongoing monitoring and evaluation efforts. The survey results are analyzed and a report prepared on an annual basis. An example of the most recent evaluation completed by TTI is contained in the report "The Status and Effectiveness of the Houston HOV lane System, 1989."[20]

The results of the data collection and on-going monitoring activities can be presented in a variety of ways. The most common approach utilized in many of the more comprehensive evaluation studies reviewed in Chapter 3 includes comparisons of before-and-after data and on-going monitoring in both table and graphic formats. As shown in Figures 15-17, TTI utilizes a number of different methods to graphically present data on the effectiveness of the HOV lanes.

Figure 15 presents a summary of the basic before-and-after data for the Katy HOV lane. Information is presented on the HOV lanes, freeway mainlanes, the combined facility, transit data, and comparisons of data for freeway facilities with and without HOV lanes. This table provides an easily understood comparison of the basic information and measures of effectiveness for the total facility. Figure 16 presents an example of one of the graphs used to show the

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[20]Dennis L. Christiansen and Daniel E. Morris. *The Status of the Effectiveness of the Houston Transitway System, 1989.* Prepared for the Texas State Department of Highways and Public Transportation by the Texas Transportation Institute, March, 1990.

KATY FREEWAY (I-10) AND TRANSITWAY, HOUSTON

Summary of A.M. Peak-Period, Peak-Direction Katy Freeway and Transitway Data, December 1989
Prepared by Texas Transportation Institute

Type of Data Phase 1 of Transitway Became Operational 10/29/84	"Representative" Pre-Transitway	"Representative" Current Value	% Change
Transitway Data			
Transitway Length (miles)		11.5	
Transitway Cost (millions)		$32	
Person-Movement			
Peak Hour (7-8 a.m.)	—	3,316	—
Peak Period (6-9:30 a.m.)	—	7,523	—
Total Daily	—	18,352	—
Vehicle Volumes			
Peak Hour	—	950	—
Peak Period	—	2,155	—
Vehicle Occupancy, Peak Hour (persons/veh)	—	3.49	—
Accident Rate (Accidents/MVM), 11/84 - 12/89	—	1.12	—
Vehicle Breakdowns (VMT/Breakdown), 11/84 - 12/89	—	34,253	—
Violation Rate (6-9:30 a.m.)		14%	
Peak Hour Lane Efficiency[1] (1000's)	—	156	—
Annual Value of User Time Saved (millions)[7]	—	$3.8 to $7.7	—
Freeway Mainlane Data (see note)			
Person Movement			
Peak Hour	5,100	6,130	+20.2%
Peak Period (6:00-9:30 a.m.)	15,655	19,280	+23.2%
Vehicle Volume			
Peak Hour	4,045	5,540	+37.0%
Peak Period	12,750	17,660	+38.5%
Vehicle Occupancy, Peak Hour (persons/veh)	1.26	1.11	-11.9%
Accident Rate (Accidents/MVM)[2]	1.34	1.34	0.0%
Avg. Operating Speed[3]			
Peak Hour	23	23	0.0%
Peak Period	33	32	-3.0%
Peak Hour Lane Efficiency[1] (1000's)	38	47	+23.7%
Combined Freeway Mainlane and Transitway Data			
Total Person Movement			
Peak Hour	5,100	9,446	+85.2%
Peak Period	15,655	26,803	+71.2%
Vehicle Volume			
Peak Hour	4,045	6,490	+60.4%
Peak Period	12,750	19,815	+55.4%
Vehicle Occupancy			
Peak Hour	1.26	1.46	+15.8%
Peak Period	1.23	1.35	+ 9.8%
Carpool Volumes (vph)[8]			
2+, 6 a.m. to 7 a.m.	505	975	+93.1%
3+, 7 a.m. to 8 a.m.	45	430	+855.6
Total, 2+ and 3+, 6-8 a.m.	550	1,405	155.5%
Travel Time (minutes)[3]			-1.2%
Peak Hour	33.9[4]	33.5[5]	-5.6%
Peak Period	23.1[4]	24.4[5]	+94.7%
Peak Hour Lane Efficiency[1] (1000's)	38	74	

Figure 15. Example of HOV Lane Evaluation Summary Table

Summary of A.M. Peak-Period, Peak-Direction Transitway Data, December 1989 Continued

Type of Data	"Representative" Pre-Transitway Value	"Representative" Current Value	% Change
Transit Data			
Bus Vehicle Trips			
Peak Hour	11	37	+236.4%
Peak-Period	32	84	+162.5%
Bus Passenger Trips			
Peak Hour	335	1,240	+270.1%
Peak Period	900	2,645	+193.9%
Bus Occupancy (persons/bus)			
Peak Hour	30.5	33.5	+ 9.8%
Peak Period	28.1	31.5	+ 12.1%
Vehicles Parked in Corridor Park & Ride Lots	575	1,873	+225.7%
Bus Operating Speed (mph)[2]			
Peak Hour	22.6[4]	47.0[5]	+108.0%
Peak Period	33.2[4]	50.3[5]	+ 51.5%

Note: Site-specific data collected at Bunker Hill. For purposes of visibility and safety, the freeway volumes are counted between an exit and an entrance ramp. Thus, the mainlane volumes can be considered to be low.

Comparison of Measures of Effectiveness, Freeway (Katy I-10) With and Freeway Without Transitways, Houston[6]

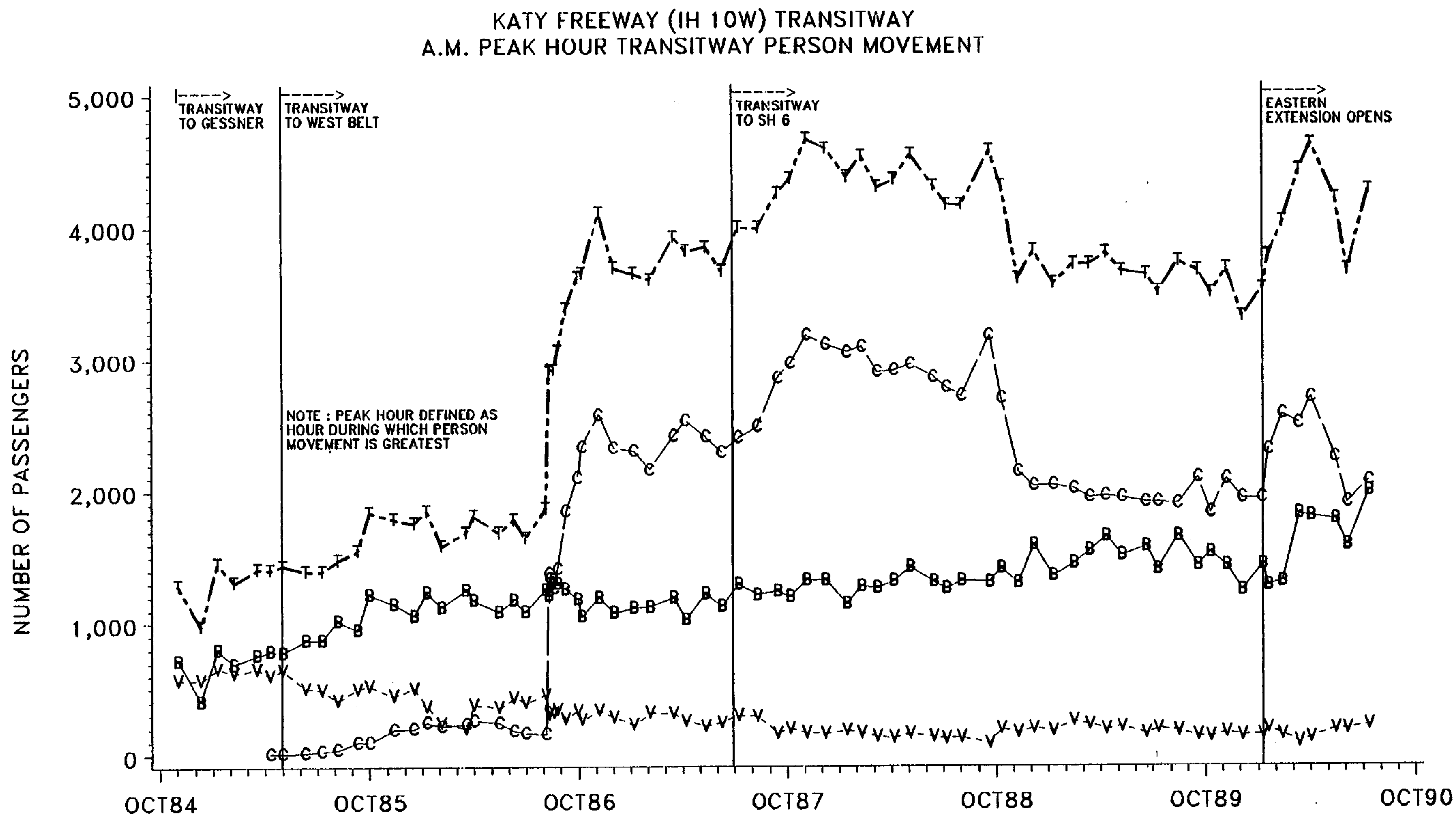
Measure of Effectiveness	"Representative" Pre-Transitway Value	"Representative" Current Value	% Change
Average A.M. Peak-Hour Vehicle Occupancy			
Freeway w/transitway	1.26	1.46	+ 15.9%
Freeway w/o transitway	1.34	1.32	- 1.5%
A.M. Peak Hour, 2+ Carpool Volume Change			
Freeway w/transitway (6-7 a.m.)	505	975	+ 93.1%
Freeway w/o transitway	600	595	- 0.8%
Bus Passengers, Peak Period			
Freeway w/transitway	900	2,645	+193.9%
Freeway w/o transitway	2,185	2,100	- 3.9%
Cars Parked at Park-and-Ride Lots			
Freeway w/transitway	575	1,873	+225.7%
Freeway w/o transitway[6]	1,660	1,665	+ 0.3%
Facility Per Lane Efficiency[1]			
Freeway w/transitway	38	74	+ 94.7%
Freeway w/o transitway	49	74	+ 51.0%

Footnotes

[1]This represents the multiple of peak-hour passengers and average speed (passengers x miles/hour). It is used as a measure of per lane efficiency.
[2]Accidents analyzed between Gessner and Post Oak, a distance of approximately 4.7 miles. This corresponds to Phase 1 of the transitway. Before data are for the period 1/82 through 10/84. "After" data are for the period from 11/84 to 8/89. Only officer-reported accidents are included in current files. 1989 freeway volumes estimated by TTI.
[3]From SH 6 to Washington, a distance of 12.18 miles. The transitway is in place over 11.5 miles of this section.
[4]Data pertains to operation in the freeway mainlanes.
[5]Data pertains to operation in the transitway.
[6]Data for freeways without transitways are a composite of data collected on the Gulf Freeway during the time in which no transitway existed on that facility (6/83 thru 4/88) and on the Southwest Freeway (9/86 to present).
[7]Based on time savings for transitway users in 1989 and transitway volumes in 1989, an annual estimate of travel time savings to transitway users is developed. A value of time of $9/hour is used based on the value applied in the Highway Economic Evaluation Model.
[8]Carpool counts are adjusted in an effort to compensate for under counting of occupancies in the field.

Source: Texas Transportation Institute. The Texas A&M University System.

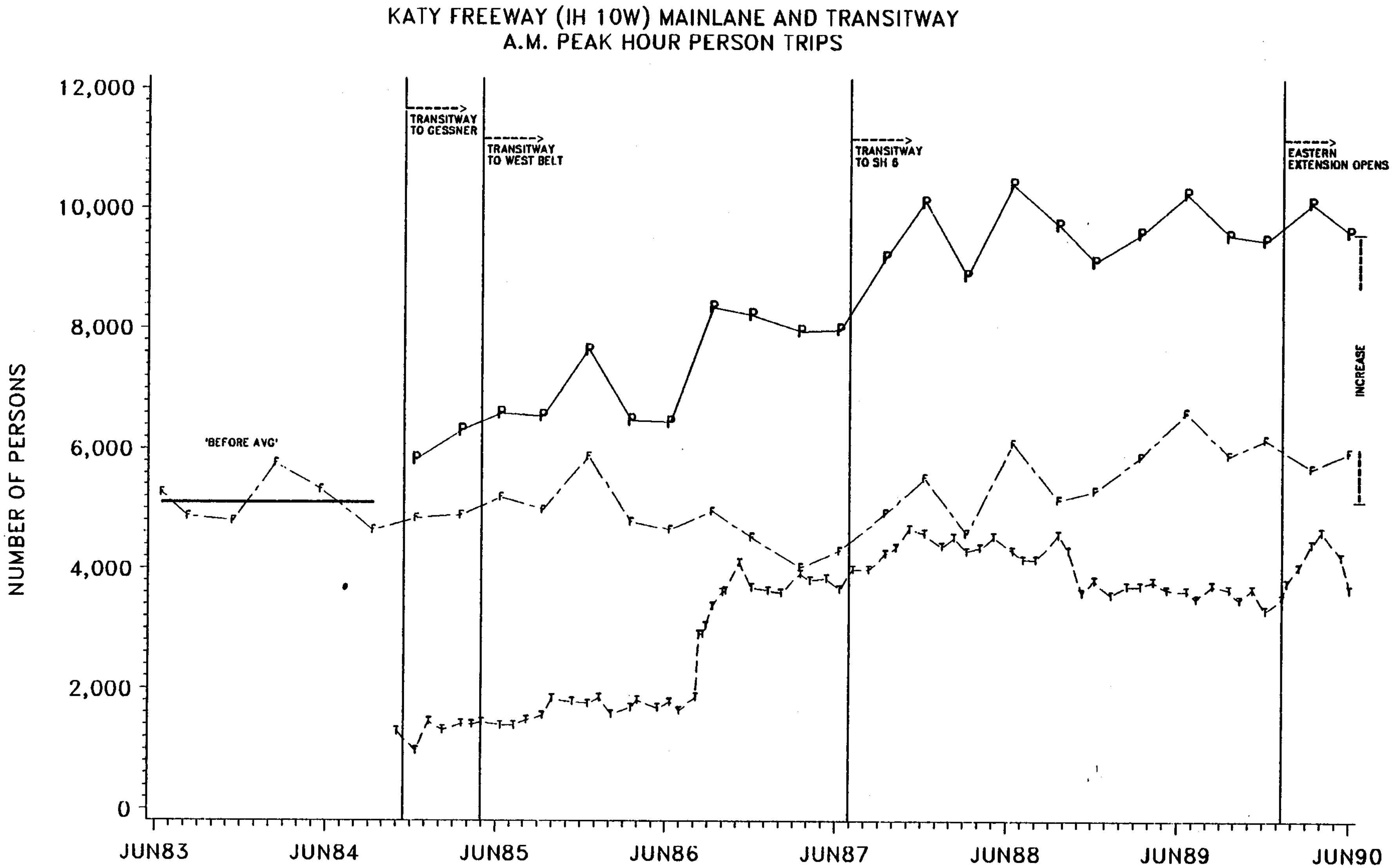
Figure 15. Example of HOV Lane Evaluation Summary Table (continued)



KATY TRANSITWAY PHASE 1, POST OAK TO GESSNER (4.7 MI.), OPENED OCTOBER 29, 1984
TRANSITWAY EXTENSION FROM GESSNER TO WEST BELT (1.7 MI.) OPENED MAY 2, 1985
OFF–PEAK, UNAUTHORIZED & 2+ CARPOOL OPERATION BEGAN AUGUST 11, 1986
TRANSITWAY EXTENSION FROM WEST BELT TO SH 6 (5.0 MI.) OPENED JUNE 29,1987
3+ CARPOOL REQUIREMENT FROM 6:45 TO 8:15 A.M. IMPLEMENTED OCTOBER 17, 1988
TRANSITWAY EASTERN EXTENSION (1.17 MI.) OPENED JANUARY 9, 1990
DATA COLLECTED BETWEEN GESSNER AND POST OAK
SOURCE : TEXAS TRANSPORTATION INSTITUTE

LEGEND : T = TOTAL HOV PASSENGERS
B = TOTAL BUS PASSENGERS
V = TOTAL VANPOOLERS
C = TOTAL CARPOOLERS

Figure 16. Example of HOV Lane Historical Usage Summary



DATA COLLECTED EASTBOUND OVER BUNKER HILL, 3 LANE SECTION
3+ REQUIREMENT FROM 6:45 A.M. TO 8:15 A.M. IMPLEMENTED OCTOBER 17, 1988
SOURCE : TEXAS TRANSPORTATION INSTITUTE

LEGEND : P = TOTAL PERSONS
F = MAINLANE PERSONS
T = TRANSITWAY PERSONS

Figure 17. Example of HOV Lane and Mainlane Historical Usage Summary

historical trends in person-movement on the Katy HOV lane, while Figure 17 shows the historical comparison of person trips for the freeway, HOV lane, and total facility. These three figures provide examples of the types of information that can be graphically presented.

A key to presenting the results of the evaluation and ongoing monitoring program is to focus on the major measures of effectiveness. These should be presented in a clear, concise, and readable manner, that allows individuals to easily identify the purpose of the data and the changes that have occurred. In addition, the narrative accompanying these tables and graphics should be concise and easily understood. A good data collection and evaluation effort can be wasted if the results are presented in a sloppy and unprofessional way. Thus, spending adequate time and resources on ensuring a clear, well done report is essential to the evaluation process. The results of the evaluation should be communicated and presented in a professional, accurate, and understandable way.

As noted in Chapter 2, it is also important that consideration be given to the audience the information is directed at. The results of the evaluation and ongoing monitoring activities will be of interest to transportation professionals and technical staff, decision makers, special interest groups and the general public. The presentation, level of detail, and analysis provided should be appropriate for the audience being addressed. For example, transportation professionals would be more interested in the detailed technical information, while decision makers and the general public may be more interested in general trends and utilization levels.

Staffing and Resources

The staffing and resources needed to conduct the data collection activities will depend on the frequency and approach used. The current schedule for the data collection activities associated with the Houston evaluation described previously is shown in Table 9.

Table 9. Frequency of Data Collection for the Houston HOV lanes

Data Collected	Facilities	Frequency
Vehicle and Occupancy Counts	Freeways and alternate routes	Quarterly
Vehicle and Occupancy Counts	HOV lanes and park-and-ride lots	Monthly
Travel Time Runs	HOV lanes and freeways	Quarterly
Surveys	HOV lanes and freeways	Yearly[1]
Accident Information	HOV lane and freeways	Ongoing
Violation Rates	HOV lane	Ongoing

[1]Surveys are generally conducted approximately once a year, but not necessarily always one year apart.

An example of the general level of effort and cost associated with conducting the vehicle and occupancy counts, travel time runs, and surveys associated with the Houston HOV lane monitoring and evaluation program are shown in Tables 10 and 11. The costs vary somewhat by HOV lane depending on the length, number of access/egress points, and number of support facilities. The Northwest HOV lane corridor, which represents the middle range in terms of effort and cost, has been used to show the average expenditures. Only the direct cost are shown, since the fringe and indirect rates used at different agencies may vary greatly. Thus, depending on the fringe and indirect rates, the costs should be increased appropriately. This will probably result in a total cost in the range of $95,000 to $120,000 per HOV lane corridor. Including the cost of monitoring a "control" freeway would add approximately $25,000 to this figure. These figures do not include the costs associated with the detailed analysis of the data or the preparation of the different reports. Depending on the scope, level of detail, and type of report, these costs could be expected to range from roughly $50,000 to $150,000; bringing the total budget to between $150,000 and $300,000.

Table 10. General Staffing Requirements for Data Collection Activities for the Northwest Corridor

Data Collection Activity	Staffing Requirement
Vehicle and Occupancy Counts	
Freeway mainlanes	3[1]
Freeway frontage road	1
HOV lane	2
Parallel alternate route	1[2]
Travel Time Runs	
Freeway mainlanes	4[3]
HOV lane	4[3]
Surveys	
On-board bus	8[4]
Carpool/vanpool	2[5]
Freeway mainlanes	1[5]

[1]One person is needed for each freeway mainlane. Thus, if it is a 4-lane facility, 4 people would be needed.
[2]One person is needed for each parallel route.
[3]A total of 4 people, 2 people per vehicle.
[4]Refers to personnel needed to hand out and collect surveys on the buses. This allows all surveys to be completed in one day.
[5]Refers to personnel needed to read license plates at specific locations on the facility. The staffing requirements depend on the number of recording locations.

Table 11. General Annual Data Collection and Reduction Costs for the Northwest HOV lane Corridor

Data Collection	Staff Hours		Staff Cost[1]	Direct Costs[2]	Total Cost[3]
	Staff	Technicians			
Vehicle and Occupancy Counts[4]	100	1,620	$15,000	$ 4,700	$19,700
Travel Time Runs[5]	320	360	$ 9,300	$ 2,700	$12,000
Surveys[6]	600	1,000	$20,000	$ 4,000	$24,000
TOTAL	1,020	2,980	$44,300	$11,400	$55,700

[1]Based on an estimate of $8 an hour for technicians and $20 an hour for professional staff. Does not include fringe or indirect rates.
[2]Includes mileage, computer time, etc.
[3]Does not include fringe and indirect costs.
[4]Includes vehicle and occupancy counts for the freeway, HOV lane one alternate parallel route, and park-and-ride lots.
[5]Includes travel time runs on freeway and HOV lane.
[6]Includes surveys of bus, carpool, and vanpool users on the HOV lane, and non-users in the adjacent general purpose freeway lanes.

Issues Associated With Data Collection Activities

Statistical Methods

Statistical methods are used in the collection, tabulation, analysis, and interpretation of the data used in before-and-after studies of HOV projects. As such, the use of appropriate statistical or scientific methods should be considered in defining the scope of the before-and-after analysis, gathering the data, examining the significance of the data, and presenting the results. A few of the key issues to be considered in developing statistically valid sampling and analysis techniques are briefly reviewed in this section. This information is provided only as an overview and an attempt to identify some of the technical areas where statistical analysis needs to be considered; it is not intended as a detailed guide. It is recommended that references[21] or expertise in statistics be consulted in the development of the specific data collection activities presented previously in this chapter. Further discussion of these issues is provided in Appendix D.

Ensuring that the sampling techniques utilized with the different data collection activities are statistically valid is one of the more important issues associated with evaluations of HOV facilities. The purpose of many of the data collection activities is to identify characteristics or attributes of individuals of the group being investigated. Thus, as a first step, the population or universe being examined must be well defined. In the case of HOV project evaluations, the population usually consists of individuals traveling in the freeway general-purpose lanes, the HOV lane(s), parallel alternate routes, and the control freeway. In addition, the time frame for the evaluation must be selected. These include the hours, days and months for which the sample is to be representative.

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[21]One such reference is Bruce D. Greenshields and Frank M. Weida. *Statistics with Applications to Highway Traffic Analyses.* Second edition, revised by Daniel L. Gerlough and Matthew J. Huber, West, Port Connecticut: Eno Foundation for Transportation, Inc., 1978.

In an ideal situation, the data collection activities would encompass all of the defined population. However, depending on the size of the population involved, this may not be possible. Thus, sampling techniques must be used to select a subgroup of the population from which to obtain the data. To ensure the reliability of the data and subsequent analysis, the sample must be selected so that it accurately represents the population. Thus, a method must be used that will result in a random or unbiased sample. Simple random and stratified random sampling techniques represent the two most commonly used methods associated with HOV project evaluations.

The simple random sampling technique, which is based on the concept that everyone within the population has an equal chance of being included in the sample, represents the most basic sampling approach. The stratified random sampling technique selects random samples from specific subgroups of the population. Determining the appropriate sample size relates to the quantity of data needed to meet different statistical considerations. In most cases, the identification of the sample size corresponds to the maximum error that is acceptable for the analysis and the degree of certainty desired that this maximum error will not be exceeded.

In Houston, the vehicle classification and occupancy data are collected in 15-minute intervals. The vehicle classification and occupancy counts for the freeway general-purpose lanes are taken only for the middle lane, with vehicle and general classification counts taken on the other lanes. Thus, the universe of vehicles are counted for all lanes for the vehicle classification, with a sample of only the middle lane for the occupancy data. For this method to be statistically valid, the occupancy levels of the middle lane must be shown to be similar to the other lanes. This method was utilized in Houston only after it was established that the middle lane was in fact representative of all the general-purpose freeway lanes.

Simple random samples and cluster samples appear to be the two most often utilized techniques with surveys of users and non users of the HOV facility. However, in cases where only a few buses are operated on the HOV facility, the total population of bus riders may be surveyed. As a general guideline, the research effort will be better served by obtaining a high response rate from a statistically valid sample group than a low response rate from the full population. In the latter case, it is difficult to establish if the results are in fact representative of the full population due to the large number of non-respondents.

Scheduling

Data collection activities should be conducted on days that represent normal weekday conditions. Thus, in Houston, vehicle and occupancy counts, travel time runs, and surveys are scheduled for Tuesday through Thursday. Monday and Friday are avoided, as travel on these days tends to be less representative of normal travel patterns. The time of year is also important. Data collection during holiday periods and the summer should be avoided, unless they are conducted as part of a frequent, regularly scheduled data collection effort. The fall and spring represent the best times of the year for routine data collection.

These general rules of thumb do not, of course, apply in the case of special data collection efforts focusing on a specific time period, such as the monitoring of weekend use, or if a system is in place through which data are continuously obtained. When possible, the data collection activities should be conducted on the same days for the HOV facility and freeway lanes. For example, if possible, travel time runs should be made on the same day for the HOV facility and the freeway lanes. While it is beneficial to have information for both the morning and afternoon peak-periods, it may be appropriate in some instances to conduct more intensive efforts during the morning peak-period.

Frequency and Costs

The frequency with which regular data collection activities are conducted varies greatly between the different HOV facilities across the country. On one extreme, some areas collect almost no data on a regular basis. Houston, on the other hand, represents probably the most comprehensive on-going data collection and monitoring program, with the collection of both monthly and quarterly data.

In determining the appropriate frequency of data collection activities, consideration should be given to the type of HOV facility, the maturity of the system, available resources, and changes or anticipated changes in the operating environment. The desired outcome is to best utilize the available resources to ensure a basic on-going level of data collection to effectively monitor and evaluate the HOV facility. Each of these considerations will be touched on briefly.

Data collection activities should be tailored to the type of HOV facility and operating characteristics. Short contraflow or concurrent flow lanes that operate only during the peak periods may require lower levels of effort than extensive exclusive or concurrent flow lanes.

The maturity of the facility may also influence data collection efforts. New facilities should be evaluated more frequently than those that have reached a stable operating level. This is not to say that older facilities should not continue to be monitored, but the frequency of these activities may be slightly less. Data from current projects suggest that usage levels on successful HOV facilities will continue to increase for several years. Thus, it is important that data collection and monitoring activities be organized to accurately monitor these changes.

If changes have occurred or are anticipated in the operating environment, more frequent data collection may be appropriate. Examples of possible changes could include increasing or decreasing the minimum occupancy requirements, changing the hours of operation, and the opening of other competitive facilities. Anticipating these changes should allow for conducting the appropriate data collection activities to evaluate the impact of these changes. The evaluation of the change in the operating hours on the Shirley Highway discussed in Chapter 3 provides a good example of this type of before-and-after study.

Regardless of the type and maturity of the facility, it appears that a base level of data needs can be identified. Table 12 outlines a suggested desired level and a basic level of data collection. In terms of providing information needed to evaluate the HOV project objectives, the vehicle and occupancy counts and travel time runs for the HOV lane, freeway mainlanes, and a control freeway are the most important. Information from these are used in determining if many of the major objectives have been met. Thus, limited resources would best be used in obtaining accurate vehicle and occupancy counts and travel time data. However, the surveys provide valuable information on the perception of users and non-users. Thus, it is strongly encouraged that surveys be conducted at a minimum shortly after implementation of an HOV facility, and at periodic times thereafter.

Table 12. Suggested Minimum Frequencies of Data Collection

Data Collected	Facilities	Frequency[1]	
		Desirable	Minimum
Vehicle and Occupancy Counts	HOV facility, freeway, alternate parallel routes, and park-and-ride lots	Quarterly/ Monthly for HOV lane	Annually[2]
Travel Time Runs	HOV facility and freeway	Quarterly	Annually[2]
Surveys	HOV facility and freeway	Annually	2-3 Years
Accident Information	HOV facility and freeway	Quarterly	Annually[2]
Violation Rates	HOV facility	Monthly	Annually[2]

[1]It may be appropriate to focus these activities on the a.m. peak period if initial data collection activities indicate this is appropriate.
[2]HOV facilities that have reached a stable operating condition, it may be appropriate to collect this information every 18 to 24 months.

The following is suggested as a basic level of data collection for a new HOV project to ensure that an adequate before-and-after evaluation can be completed. Prior to the start of any construction activity, vehicle and occupancy counts and travel time runs should be conducted on the freeway and along parallel alternate routes. At a minimum, these should be conducted during the a.m. peak-period. The results of the Houston evaluations strongly indicated the importance of trend data, rather than a single data point. Thus, establishing several "before" data points appears important. Historical information on safety and accident rates on the facility should also be collected.

After implementation of the HOV facility, vehicle and occupancy counts and travel time runs should be conducted on the HOV lane(s), freeway lanes, and alternate routes. These should be conducted at least once during the first 3 to 6 months of operation, and again at 12 months. An ongoing data collection effort should also be established. Safety, accident, and violation information should also be examined on the same schedule. A survey of users and non-users should be conducted at some point during the first year and on the same schedule. A regular schedule should be established for ongoing surveys.

Control Facility

As noted, it is important that a control freeway facility be included in the evaluation process. This is necessary to insure that general changes in traffic conditions in the metropolitan area, that may impact the freeway and HOV facilities, are monitored. Without this it is statistically very difficult to draw accurate conclusions on many of the measures of effectiveness.

Training and Safety

Collecting traffic data in a congested urban environment is extremely dangerous. Thus, safety should be primarily the consideration in all decisions regarding the data collection activities. Adequate training should be provided to the personnel that will be conducting the various data collection activities. TTI uses a slide presentation that addresses safety measures and data collection procedures with all personnel responsible for conducting vehicle and occupancy counts and travel time runs. Training sessions are also held for these personnel, as well as those conducting the on-board bus surveys. In addition, new trainees are taken out to the freeway and HOV lanes for practice runs before the actual data collection activities are initiated.

Standardization of Terms and Definitions

The review of before-and-after studies presented in Chapter 3 indicated that different areas use different definitions of some of the terms associated with HOV evaluations. These include different definitions of the length and hours of the peak-period, the time of the peak-hour, and the methodology used to determine the benefit-cost ratio. While it is realized that local conditions will influence some of these definitions, it appears that agreement on the use of a standard format would benefit all areas. At a minimum, the identification of a "core" peak-period and the collection of appropriate data during these periods would allow for comparisons among the different projects. Individual areas could then expand on these "core" hours as appropriate for conditions in their area. It is suggested that a 3-hour peak-period be established to provide uniform collection of comparable information.

Use of Advanced Technology for Data Collection Activities

As discussed in this chapter, some areas have utilized cameras and other forms of advanced technologies to assist with data collection activities. Further expanded use of these techniques are being planned and implemented in some areas. To date, the results of using this type of equipment have been mixed. While cameras, and other techniques, can assist with data collection efforts, they do have drawbacks and limitations. For example, the use of cameras is often limited to daylight hours. In addition, cameras may not always be able to detect all passengers in the vehicles, especially those in a reclining position or infant seat.

However, cameras and other technologies, when used in the appropriate way, can aid in the data collection efforts. In addition, the whole area of technology is in a state of constant change and advancement. Continuing to monitor this situation and test new types of technologies to assist in the data collection process is appropriate and should be encouraged.

Summary

This chapter has presented a discussion of the data collection methods and techniques utilized in Houston as the basis for a suggested approach to the data collection activities needed to evaluate HOV facilities. Following the procedures outlined in this chapter will assist in ensuring that an adequate before-and-after evaluation is conducted. It will also help to increase the potential for comparability between HOV projects in different areas.

CHAPTER V. CONCLUSION

The continued increase in the number of operating HOV lanes throughout North America indicates that these types of facilities have become a more widely accepted method of addressing traffic congestion issues in many metropolitan areas. A consensus appears to exist that, in the proper environment, HOV lanes can be an effective means of increasing the person-movement efficiency within a corridor. However, HOV facilities are not appropriate for all situations, nor does their implementation eliminate the need to also pursue other strategies.

As discussed in this report, it does not appear that a consensus presently exists among transportation professionals regarding the best methods for evaluating HOV facilities. A variety of objectives, measures of effectiveness, performance thresholds, and data collection techniques have been used in the before-and-after evaluations and on-going monitoring that have been conducted to date. While examples of good evaluation studies do exist, there are also many cases where little or no data collection or evaluation efforts have been conducted. This has often resulted in insufficient data to make meaningful before-and-after comparisons on the impact of an HOV project. In addition, the lack of uniformity between approaches used in different areas has made comparisons between projects difficult.

Based on the state-of-the-art review of evaluation programs, this report presents a suggested approach to conducting before-and-after evaluations and on-going monitoring of freeway HOV facilities. The suggested approach includes the identification of the objectives, measures of effectiveness, performance thresholds, and data collection techniques that are most appropriate for use in evaluating HOV facilities. In addition, the report outlines both a basic level and a desired level of data collection and analysis needed to evaluate an HOV project. It is anticipated that the suggested procedures will provide a model for application with all types of freeway HOV projects. The use of these procedures should enhance individual project evaluations and provide for greater comparability between projects.

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APPENDIX A

Appendix A - On-Board Bus Survey

KATY TRANSITWAY TRANSIT USER SURVEY

This survey is being undertaken by the Texas Transportation Institute, the Texas State Department of Highways and Public Transportation and METRO in order to obtain information about your use of the Katy Transitway. Please take a few minutes to answer the questions below and return this form to the survey taker before leaving the bus.

1. **What is the purpose of your bus trip this morning?** ___Work ___School ___Other

2. **What is the Zip Code of the area where this trip began?** (For example, if this trip began from your home this morning, you would list your home Zip Code.) ______________

3. **What is your final destination on this trip?** ___Downtown ___Galleria/City Post Oak/Uptown ___Texas Medical Center ___Greenway Plaza ___Other (specify Zip Code______________)

4. **Have you ever carpooled or vanpooled on the transitway?** ___Yes, carpooled ___Yes, vanpooled ___No

5. **How important was the opening of the Katy Transitway in your decision to ride the bus?**
   ___Very important ___Somewhat important ___Not important

6. **If the Katy Transitway had <u>not</u> opened, would you be riding a bus now?**
   ___Yes ___No ___Not sure

7. **How many minutes, if any, do you believe this bus presently saves by using the Katy Transitway instead of the regular traffic lanes?** ________Minutes in the morning ________Minutes in the evening

8. **How long have you been a regular bus rider on the Katy Transitway?** ______________________

9. **Does your employer pay for any part of your bus pass?**
   ___Yes, my employer pays $________ toward the cost of my bus pass and I pay $________.
   ___No, I pay the entire amount

10. **Was a car (or other vehicle) available to you for this trip? (check one)**
    ___No, bus was only practical means
    ___Yes, but with considerable inconvenience to others
    ___Yes, but I prefer to take the bus

11. **Before you began riding a bus on the Katy Transitway, how did you <u>normally</u> make this trip? (check one)**
    ___Drove alone
    ___Carpooled
    ___Vanpooled
    ___Rode a park-and-ride bus on the regular freeway lanes
    ___Rode a regular route or express bus
    ___Did not make this trip prior to using the Katy Transitway
    ___Other (specify______________________)

12. **Do you feel that the Katy Transitway is, at present, being sufficiently utilized to justify the project?**
    ___Yes ___No ___Not sure

13. **What is your . . .** **Age?**_____ **Sex?**________ **Occupation?**______________________

14. **What is the last level of school you have completed?** ______________________

Comments:____

____

____

____

THANK YOU FOR YOUR COOPERATION.

APPENDIX B

Appendix B - Carpool/Vanpool Survey

METRO
®

Metropolitan Transit Authority
500 Jefferson Street
P.O. Box 61429
Houston, Texas 77208-1429

713 739-4000

Dear Carpooler/Vanpooler:

Your vehicle was observed traveling eastbound on the Katy Transitway the week of September 11. Since you have first-hand knowledge of the transitway, we need your help in a special study being conducted by the Texas Transportation Institute, a transportation research agency of the Texas A&M University System. Because the Katy Transitway is one of the first transitways to operate in Texas, it is extremely important that we determine what effect it has had on your travel.

Please take a few minutes to answer the enclosed questionnaire. Your answers will provide valuable information concerning carpooling/vanpooling on the Katy Transitway. Because of the small number of poolers contacted, your specific reply is essential to ensure the success of the project. All information you provide will remain strictly confidential.

Your cooperation and timely return of the completed questionnaire in the enclosed postage-paid envelope will be greatly appreciated. Thank you for your time and assistance in this important undertaking.

METRO

Enclosures

KATY TRANSITWAY CARPOOL/VANPOOL SURVEY

Undertaken by the Texas Transportation Institute, The Texas A&M University System in cooperation with the Texas State Department of Highways and Public Transportation, the Metropolitan Transit Authority of Harris County and the U.S. Department of Transportation

1. **Is your vehicle a carpool or a vanpool?** ____Carpool ____Vanpool

2. **What is the primary purpose of your a.m. carpool/vanpool trip?** ____Work ____School ____Other

3. **How many members are regularly in your carpool/vanpool (including yourself)?** ________________

4. **Who makes up your carpool/vanpool group?** ____Family Members ____Neighborhood friends ____Co-Workers

5. **Does your carpool/vanpool use a park-and-ride or park-and-pool lot as a staging area?**
____Yes (please specify which lot you typically use ________________) ____No

6. **How long have you been a regular user of the Katy Transitway?** ________________

7. **Which transitway entrance do you normally use to access the Katy Transitway in the morning?**
____I-10 West of SH 6 ____Addicks Park-and-Ride Flyover Ramp ____Gessner

8. **What time do you normally enter the transitway in the morning?** ____________a.m.

9. **What is your a.m. carpool/vanpool destination?** ____Downtown ____Galleria/City Post Oak/Uptown
____Greenway Plaza ____Texas Medical Center ____Other (specify Zip Code____________)

10. **When did you join your present carpool/vanpool?** Month:____________ Year:________

11. **How important was the Katy Transitway in your decision to carpool/vanpool?**
____Very important ____Somewhat important ____Not important

12. **If the Katy Transitway had not opened to carpools/vanpools, would you be carpooling/vanpooling now?**
____Yes ____No ____Not sure

13. **Prior to carpooling/vanpooling on the Katy Transitway, how did you normally make this trip?**
____On the transitway
 ____Bus ____Vanpool ____Carpool

 ____On the Katy Freeway general purpose lanes
 ____Bus ____Vanpool ____Carpool ____Drove Alone

 ____On a parallel street or highway (Street Name____________________)
 ____Bus ____Vanpool ____Carpool ____Drove Alone

 ____Did not make this trip

14. **How many minutes, if any, do you believe your carpool/vanpool saves by using the Katy Transitway instead of the regular traffic lanes?** ________Minutes in the morning ________Minutes in the evening

15. **Do you feel that the Katy Transitway is, at present, sufficiently utilized to justify the project?**
____Yes ____No ____Not sure

16. **What is your . . . Age?**________ **Sex?**________ **Occupation?**________________

17. **What is the last level of school you have completed?** ________________

18. **What is your home Zip Code?** ____________

We would appreciate your additional comments: ________________

THANK YOU FOR YOUR COOPERATION.
Please return this form at your earliest convenience in the postage-paid envelope provided.

APPENDIX C

Appendix C - Freeway Motorist Survey

METRO®

Metropolitan Transit Authority
500 Jefferson Street
P.O. Box 61429
Houston, Texas 77208-1429

713 739-4000

Dear Motorist:

Your vehicle was observed traveling eastbound on the Katy Freeway between 6:00 and 9:00 a.m. the week of October 9. Since you have first-hand knowledge of traffic conditions on the Katy Freeway, we need your help in a special study being conducted by the Texas Transportation Institute, a research agency of the Texas A&M University System.

To help serve the travel demand, the State Department of Highways and Public Transportation and the Metropolitan Transit Authority have constructed the Katy Transitway for use by buses, carpools and vanpools. Vehicles using the transitway travel inbound toward downtown in the morning and outbound in the afternoon. The Katy Transitway has been constructed within the median of the freeway and is protected from other traffic by concrete barriers. The location of the transitway in the median has not reduced the number of general traffic lanes available to motorists.

Because the Katy Transitway is one of the first transitways to operate in Texas, we need your help to determine how it is working. Please take a few minutes to answer the enclosed questionnaire. The questions on this survey concern your routine trips made on the Katy Freeway in the morning, from 6:00 a.m. to 9:00 a.m. Because of the small number of motorists contacted, your specific reply is essential to ensure the success of the project. Your answers will remain strictly confidential.

Your cooperation and timely return of the completed questionnaire in the enclosed postage-paid envelope will be greatly appreciated. Thank you for your time and assistance in this important undertaking.

METRO

Enclosures

KATY FREEWAY MOTORIST SURVEY

Undertaken by the Texas Transportation Institute, The Texas A&M University System in cooperation with the Texas State Department of Highways and Public Transportation, the Metropolitan Transit Authority of Harris County and the U.S. Department of Transportation

1. **What was the purpose of your trip?** ____Work ____School ____Other

2. **What are your reasons for driving your car on the freeway mainlanes rather than traveling in a high-occupancy vehicle on the transitway?**
____Need car for job
____Car is more convenient and flexible
____No convenient bus, vanpool or carpool available
____Work irregular hours
____Other (specify________________________________)

3. **How many days per week do you normally make this trip?** ____________

4. **How do you <u>usually</u> make this trip?**
____Drive alone ____Vanpool ____METRO regular route or express bus
____Carpool ____METRO park-and-ride bus ____Other (specify____________)

5. **How many people (including yourself) were in your vehicle for this trip?** ____________

6. **Which on-ramp did you use to enter the Katy Freeway for this trip?** ____________________

7. **What was the destination of your trip?**
____Downtown ____Texas Medical Center ____Other (specify Zip Code below)
____Greenway Plaza ____Galleria/City Post Oak/Uptown ____________________

8. **Based on your observation of the number of <u>vehicles</u> currently using the Katy Transitway, do you feel that it is being sufficiently utilized?** ____Yes ____No ____Not sure

9. **Based on your perception of the number of <u>persons</u> currently being moved on the Katy Transitway, do you feel that it is being sufficiently utilized?** ____Yes ____No ____Not sure

10. **Do you feel that the Katy Transitway is a good transportation improvement?**
____Yes ____No ____Not sure

11. **What is your . . . Age?________ Sex?__________ Occupation?____________________**

12. **What is the last level of school you have completed?____________________**

13. **What is your home Zip Code?____________**

We would appreciate your additional comments:____________________

____

____

____

THANK YOU FOR YOUR COOPERATION.
Please return this form at your earliest convenience in the postage-paid envelope provided.

APPENDIX D

APPENDIX D - Additional Examples of the Application of Statistical Analyses With HOV Project Evaluations

This report has presented suggested procedures for conducting the major data collection activities associated with the evaluation of HOV facilities. Regardless of the specific methodology chosen to collect data, ensuring that the sampling techniques are valid and that the sample size is large enough to provide statistically reliable results are key aspects of any evaluation. This appendix discusses some of the major issues associated with establishing statistically reliable samples and provides general guidelines for ensuring representative samples. It is intended to provide an overview of the major issues, including the limitations of the different data, and general guidance in developing a statistically reliable data collection process. Additional references may need to be consulted depending on the approach utilized in each area.

Vehicle and Occupancy Counts

Due to the relative ease with which vehicle counts and classification can be conducted, obtaining an adequate sample size for these data is typically not a problem. Historically, the majority of statistical analyses of vehicle occupancy data have employed a simple random sample methodology where information on vehicle type is not used in the calculations. However, in most cases the vehicles being counted on an HOV facility and adjacent roadways are also classified according to type. The categories of carpools, vanpools, and buses are usually used in the classification process with HOV facilities. The estimation of vehicle occupancy rates from these categories can be made most efficiently through the use of a stratified random sample of vehicles. This technique separates, or stratifies, the vehicles according to classification and estimates the average occupancy of each vehicle type separately, before combining the information into an estimate of the overall average vehicle occupancy. The gain in precision of the final estimate from a stratified sample, as compared to a simple random sample, comes from the fact that the occupancies of the different vehicle types vary so greatly.

The use of a stratified estimation technique must be accompanied by reliable information on the proportion of various vehicle types that are in the traffic stream; inaccurate information can result in a biased estimate of average vehicle occupancy and, thus, an estimate with a larger error. However, if accurate information is available on the proportion of each vehicle type, the contribution to the error from this source can be minimized. In this case, the variance of the overall estimate of vehicle occupancy is simply the weighted sum of the variances within each stratum.

The variance of the overall estimate of vehicle occupancy obtained through the application of a stratified random sample should be smaller than that obtained using a simple random sample. The only additional cost to the evaluation process is the necessity of recording vehicle type, as well as occupancy, for each vehicle in the sample. Since vehicles are normally classified to determine utilization and occupancy levels by mode, this approach should not present additional cost to the evaluation process. The following example provides a comparison of the precision associated with estimates calculated from a stratified sample and from the same combined sample, ignoring the stratification.

Example 1. Suppose observation of an HOV facility supplied the following information on 1,000 vehicles:

Vehicle Type	% of Sample	Average Vehicle Occupancy	Standard Deviation of vehicle occupancy
Car	92	2.2	0.5
Van	3	8.5	2.3
Bus	5	29.0	10.2

The overall average vehicle occupancy is estimated as 3.73 persons per vehicle from either method; where the overall average occupancy can be calculated by dividing the total number of persons by the total number of vehicles or by using Equation 1. The standard errors of the estimates, however, vary depending upon the sampling method. The standard error associated with the stratification (Equation 2) is 0.07. If the stratification technique is not used (Equation 3), the standard error is 0.20.

$$occ_{st} = \Sigma_i w_i occ_i \qquad \textit{Eq. 1}$$

where:
w_i = the proportion of vehicle classification i
occ_i = the average occupancy for vehicle classification i

$$s_{st} = \sqrt{\Sigma_i w_i^2 \frac{s_i^2}{n_i}} \qquad \textit{Eq. 2}$$

where:
s_{st} = standard error using a stratified random sample
w_i = the proportion of vehicle classification i
s_i = the standard deviation of occupancy for vehicle classification i
n_i = the number of vehicles used to calculate average occupancy for vehicle classification i

$$s_{sr} = \frac{s}{\sqrt{n}} \qquad \textit{Eq. 3}$$

where:
s_{sr} = standard error using a simple random sample
s = standard deviation of occupancy for all vehicles in the sample
n = number of vehicles in the entire sample

The gain due to stratification for this example is a significant reduction in the error of the estimate. This reduction in error translates into increased precision and means that fewer vehicle observations are required to achieve the same reliability than would be predicted using a simple random sampling methodology. As noted, accurate vehicle classification data are needed to use this technique and these data must be collected on representative days and at representative locations.

The previous example was formulated based on actual data from the Katy HOV lane in Houston. Using the same sample data, different mixes of vehicles have been simulated to illustrate how the precision of the estimate changes and to contrast the stratified versus the simple random sampling technique. As can be seen in Table D-1, as the proportion of buses increases, the standard error of the estimate increases. This effect is due to the fact that the variation in occupancy is much greater for buses than for carpools or vanpools. In addition, the stratified samples in this example always yield more precise estimates, as evidenced by the smaller standard errors, than the simple random samples.

Table D-1. Comparison of Standard Errors,
Stratified versus Simple Random Sampling Techniques

	Scenario Number			
	1	2	3	4
% Cars	92	70	50	0
% Vans	3	10	20	70
% Buses	5	20	30	30
Avg. Veh. Occup.	3.73	8.19	11.50	14.65
S_{st}[1]	0.07	0.15	0.18	0.19
S_{sr}[2]	0.20	0.37	0.41	0.35

[1] The standard error determined through use of stratified random sample (Equation 2).
[2] The standard error determined through use of simple random sample (Equation 3).

The selection of the sample, in terms of hours, days, and locations, needs careful planning. It is important to remember that the sample intervals, each of which is a specified time interval at a particular location, must be randomly selected from the total population (defined as the collection of units from which the sample is drawn). In other words, all locations and time periods that the estimated average vehicle occupancy is to represent must be included in the defined population, and the sample intervals randomly chosen from that population. For instance, if an estimate of vehicle occupancy is needed for the weekday peak period during the summer months, the sampling frame would consist of all morning and evening peak periods on all weekdays for the months of June, July, and August. Each peak period interval would, therefore, be a sampling unit.

The selection of intervals for sampling should be done randomly, with all peak period intervals on weekdays during the three months having equal probability of being chosen. The number of intervals in the sample would be determined by examining Table D-2, which gives the precision of estimates or standard errors, for specified sample sizes using stratified random sampling, and from knowledge of the volume expected during one interval.

Table D-2. Standard Errors of Overall Vehicle Occupancies Utilizing Stratified Random Sampling, Houston HOV Facilities

	Distribution of Vehicles							
% Cars	95	90	75	65	55	45	15	10
% Vans	2	4	8	11	15	20	50	45
% Buses	3	6	17	24	30	35	35	45
Sample Size, n[1]	Standard Errors							
1000	0.058	0.081	0.133	0.158	0.176	0.191	0.196	0.219
2000	0.041	0.057	0.094	0.112	0.125	0.135	0.138	0.155
3000	0.034	0.047	0.077	0.091	0.102	0.110	0.113	0.126
4000	0.029	0.040	0.067	0.079	0.088	0.095	0.098	0.109
5000	0.026	0.036	0.060	0.071	0.079	0.085	0.087	0.098

Notes: The standard errors in this table were estimated based on data collected on HOV facilities in Houston, Texas; they should only be used as guidelines and considered to represent non-incident day vehicle occupancies for the weekdays of Tuesday through Thursday.
These data should not be considered a permanent substitute for local data.
The standard deviations used to calculate the standard errors were 0.5, 2.5, and 10.0 persons per vehicle for cars, vans, and buses, respectively.

[1] The total number of vehicles for which occupancy data are obtained

The standard errors shown in Table D-2 are estimates based on data collected on the Houston HOV lane system. The standard deviations in vehicle occupancies used for Table D-2 were 0.5, 2.5, and 10.0 persons per vehicle for car, vans, and buses, respectively. Due to the limited data ranges possible for each vehicle type, large deviations from these values are not expected. By utilizing Equation 2, however, calculation of expected precision can be accomplished if different local values are known for standard deviations in vehicle occupancy. In addition, calculations can be made for exact proportions of vehicle classes, rather than the selected values given in Table D-2.

It is recommended that the values in Table D-2 be used only as guidelines and that they should not be considered a permanent substitute for local data. It is also important to note that, as data collected for the Houston HOV lane system, these data represent non-incident day vehicle occupancies for the weekdays of Tuesday through Thursday. The following example illustrates how one would use Table D-2, or similarly developed data, to estimate confidence intervals, assuming a normal distribution.

Example 2. Suppose an HOV facility with multiple access points was known to exhibit the following characteristics:

Vehicle Type	Vehicle Distribution (%)	Average Vehicle Occupancy	Standard Deviation of Vehicle Occupancy
Car	90	2.2	0.5
Van	4	8.5	2.5
Bus	6	29.0	10.0

Through the use of Tables D-2 and D-3 and Equation 4, a 95% confidence interval for a sample size of 4,000 vehicles can be estimated as:

$$4.06 \pm (1.96) \times (0.04)$$
$$\text{or } 4.06 \pm 0.08$$

Thus, it could be concluded that for the one section of the HOV facility within which the counts were conducted, there was 95% confidence that the average overall vehicle occupancy falls between 3.98 and 4.14. Stating that the entire HOV facility has an average vehicle occupancy of 4.06, without any data for the other sections of the facility, would, however, be a statistically invalid statement. Determining the average overall vehicle occupancy for an HOV lane with multiple access points could be accomplished by gathering data for the appropriate sections of the HOV lane and applying the stratified random sampling methodology outlined previously.

Table D-3. Standard Normal Deviates for Various Levels of Confidence

Level of Confidence, P(%)	Two-Tailed Probability, α	Standard Normal Deviate, z
80	0.10	1.282
90	0.05	1.646
95	0.025	1.960
99	0.005	2.576

$$C.I. = \mu \pm z(se) \qquad \textit{Eq. 4}$$

where:
$C.I.$ = confidence interval
x = mean vehicle occupancy
z = standard normal deviate
se = standard error of x

Both of the general sampling methodologies outlined are acceptable. The simple random sampling method could be considered as a conservative estimate, but would likely require an extensive data base before yielding statistically acceptable ranges of error. The stratified random sampling scheme appears to provides a more efficient means of estimating average vehicle occupancy and should be considered if budget limitations are an issue.

In addition, the stratified approach outlined previously could easily be applied to different sections of an HOV facility and to different types or classifications of days (i.e. incident versus non-incident days or Mondays and/or Fridays versus Tuesdays through Thursdays). While the type or classification of day may have a marginal impact on vehicle occupancy, it would be expected to greatly affect travel time runs. The stratified random sampling methodology could also easily be expanded to include commercial vehicles, facilitating its application in determining average vehicle occupancy for sections of general-purpose freeway lanes.

Travel Time Data

Statistically reliable estimates of average travel times can be obtained by using the same stratified sampling procedures described for vehicle occupancy data. As noted previously, travel time data would likely differ markedly on days for which major incidents occurred. A significant difference in travel times might also exist for Monday and Friday versus Tuesday through Thursday. Separate estimates could be made for any of these conditions. These estimates could then be combined into one overall estimate of travel time by computing a weighted average and the associated standard error.

An important difference between vehicle occupancy and vehicle travel time is that vehicle occupancies are independent of each other. In other words, the occupancy of one vehicle is not influenced by the occupancy of an adjacent vehicle. However, the travel times of two vehicles travelling together or within a few minutes of one another are related, since they are influenced by the same traffic flow conditions. Obtaining travel time data for a large number of vehicles within a short time frame, while statistically providing greater confidence in the average travel time for that small time period, may contribute little toward determining the average travel time during the peak hour or peak period. A better approach would be to sample each 15-minute period to obtain different sets of traffic flow conditions and thus a better estimate of the overall travel time.

The sample sizes necessary for different levels of precision are shown in Table D-4. These sample sizes were calculated through the use of Equation 5. The standard deviations represent the variability in travel times observed over time and from day to day. The standard deviations and standard errors are both expressed in terms of percentages. In order to illustrate how Table D-4 might be used, the following example is provided:

Example 3. The expected travel time for an HOV lane during the morning peak hour is 15 minutes with a 10% (1.5 minute) standard deviation. Suppose the desired precision was a standard error of 2.0%.

Table D-4. Estimated Sample Size Requirements for Travel Time Data

Standard Error (%)	Standard Deviation (%)			
	5	10	15	20
1.0	25	100	225	400
2.0	6	25	56	100
5.0	1	4	9	16
10.0	1	1	2	4

$$n = \left(\frac{sd}{se}\right)^2 \qquad \textit{Eq. 5}$$

where:

n = sample size expressed in 15-minute periods
sd = standard deviation of travel times, %
se = standard error of mean travel time, %

Through the use of Table D-4, the required sample size would be 25. This means that travel time data would need to be collected for 25 separate 15-minute periods during morning peak hours. If this were accomplished, then the 95% confidence interval for the mean travel time would be (assuming an estimated average travel time of 15 minutes and equation 4):

15 $\pm$ 1.96 x 0.3 minutes
15 $\pm$ 0.6 minutes
or 14.4 to 15.6 minutes

User and Nonuser Surveys

Sampling techniques are commonly used with surveys of users and nonusers of HOV facilities due to the large size of both groups. The sample random sampling technique, which is based on the concept that everyone within the population has an equal chance of being included, is most often used with HOV project evaluations. This section provides general guidelines on the standard errors associated with different sample sizes. As a general guideline, the HOV project evaluation will be better served by obtaining a high response rate from a statistically valid sample group than by a low response rate from the full population or a larger sample. In the latter case it is almost impossible to establish if the results are in fact representative of the full population due to the large number of non-respondents.

A reliable estimate of the percentage of the population being surveyed that exhibits a specified characteristic is usually the goal of a survey. The precision of this estimate is commonly described by its standard error. The estimated standard errors associated with different sample sizes and the different percentages are shown in Table D-5. These values were developed using Equation 6.

Table D-5. Estimated Standard Errors for Estimates of Population Percentages for Various Sample Sizes

	Population Percentages					
n/P[1]	0/100	10/90	20/80	30/70	40/60	50/50
10	0	10.0	13.3	15.3	16.3	16.7
20	0	6.9	9.2	10.5	11.2	11.5
50	0	4.3	5.7	6.5	7.0	7.1
100	0	3.0	4.0	4.6	4.9	5.0
200	0	2.1	2.8	3.2	3.5	3.5
500	0	1.3	1.8	2.1	2.2	2.2
1000	0	0.9	1.3	1.4	1.5	1.6
2000	0	0.7	0.9	1.0	1.1	1.1
2500	0	0.6	0.8	0.9	1.0	1.0
5000	0	0.4	0.6	0.6	0.7	0.7

[1] P = Population percentage in category of interest and n = survey sample size

$$se = \sqrt{p(100-p)/(n-1)} \qquad \textit{Eq. 6}$$

where:
se = standard error of the estimated sample percentage
p = sample estimate of the percentage (P)

Table D-5 identifies several relationships between the standard error and the sample size and population percentage. First, the standard error decreases as the sample size increases. In addition, the standard error is dependent on the actual population percentage, being largest for 50 percent.

The approximate confidence intervals for percentage responses of survey questions can also be determined through use of Equation 4. The standard normal deviate (z) can be determined for the desired level of confidence from Table 12.

NOTICE

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TECHNOLOGY SHARING

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